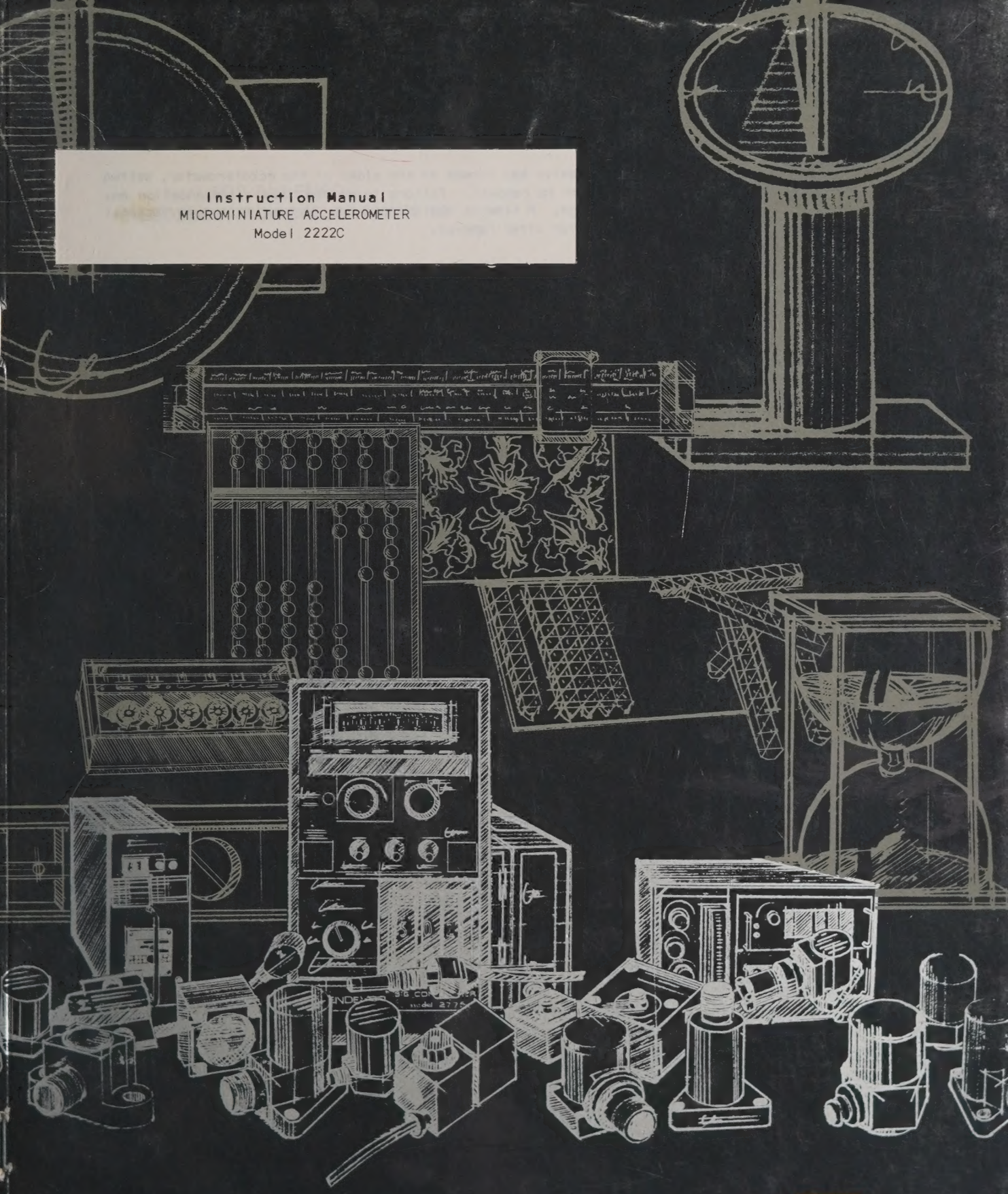
Instruction Manual

MICROMINIATURE ACCELEROMETER

Model 2222C



ENDEVCO

Instruction Manual
MICROMINIATURE ACCELEROMETER
Model 2222C

1.0 INTRODUCTION

The instructions contained in this manual are relative to installing and removing the Endevco® Model 2222C Microminiature Accelerometer. Because of its extremely small size and physical construction, certain special precautions must be observed when mounting and removing to avoid damaging the unit.

2.0 MOUNTING THE ACCELEROMETER

The self-generating shear-type piezoelectric accelerometer was designed for adhesive mounting to the specimen structure. Endevco recommends Aron Alpha CE-480, #201 Rapid Bonding Adhesive be used (or an equivalent) in mounting the accelerometer. The adhesive is distributed by Vigar Company, Division of B. Jadow & Sons, Inc., 53 West 23rd Street, New York, N.Y. 10010.

When mounting the Model 2222C Accelerometer, perform the following steps and observe the precautions noted:

a. Ensure mating surfaces are smooth and flat. Remove all traces of grease and oily residue from mating surface with a cotton swab and solvent (acetone or nail polish remover).

b. Apply only a small droplet of adhesive to the mounting surface, approximately 1/3 the diameter of the mounting pad. Sparing application of the adhesive will prevent a buildup of the material as a fillet on the sides of the accelerometer. If such a buildup does occur, the excess adhesive should be removed before it hardens. Failure to heed this caution may result in damage to the accelerometer during its removal from the test structure.

CAUTION

When mounting the accelerometer, mount on the small anodized foot (that surface opposite the one bearing the ENDEVCO® symbol). Failure to heed this caution may result in damage to the accelerometer during its removal from the test structure.

c. Spread the adhesive with a toothpick (or similar applicator) to form a thin, uniform layer covering the area of contact, and immediately position the accelerometer on mating surface. Press accelerometer down and hold firmly in place for 30 seconds to allow adhesive to set. Allow adhesive to set for several minutes to attain maximum strength.

d. If the accelerometer is to operate at low frequencies and/or large acceleration levels, the accelerometer cable must be secured to the vibrating structure as close as possible to the accelerometer.

3.0 REMOVING THE ACCELEROMETER

The following precautions should be observed when removing the accelerometer from the test structure:

a. Observe the accelerometer case for a build-up of adhesive surrounding the sides. Any presence of adhesive will prevent proper use of the accelerometer removal tool.

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b. In the event a fillet of adhesive has formed at the sides of the accelerometer, soften the fillet with acetone prior to removal. Failure to follow this recommendation may result in accelerometer damage. A Kimwipe and acetone may be used to remove residual adhesive from the accelerometer after removal.

c. Removal Tool, Model 2943B (supplied with each accelerometer), must always be used to remove the Model 2222C Accelerometer from the test structure. Pliers or other similar tools must not be used, as they will damage the case. During removal of the accelerometer the tool must lie flat on the surface to which accelerometer is mounted. Twist or torque the accelerometer, stressing the bond in shear.

4. CABLE ASSEMBLY

The Model 2222C Accelerometer is provided with a 1-foot (30 cm) low-noise coaxial cable assembly, part number 3093-12. The cable assembly is detachable, but should not be removed from the accelerometer unless the cable has been damaged. Detachment of the cable will expose the sensing element in the accelerometer to the atmosphere, and any conducting or solid particles, or moisture, entering the transducer will result in deterioration of accelerometer operation.

Perform the following and observe the precaution when removing and replacing the accelerometer cable assembly.

CAUTION

Remove the cable assembly only in a clean, dry (less than 50% RH) atmosphere. Do not expose accelerometer to a dirty or humid environment with cable removed. Do not place accelerometer in a vise or hold mechanically when removing/replacing cable assembly.

a. Hold accelerometer between fingers, and use open-end wrench (part 16205 supplied with accelerometer) on hexagonal flats to back-out old cable. Note that connector has right-turn threads, thus, turn cable connector counterclockwise (ccw) to back-out old cable.

b. Apply grease (supplied with accelerometer) to threaded-end of new cable and to threaded-hole in accelerometer. Grease is Dow Corning High-Vacuum Grease, Endevco part number EHX54.

c. Hold accelerometer with fingers and screw cable connector clockwise (cw) into accelerometer case. Do not allow connector to twist with respect to cable.

d. Tighten connector with open-end wrench using about one-pound force (1-lb_f) on tool.) One-pound force equals 4.5 newtons (N). This is approximately a 1 $lb_f \cdot in$. (0.1Nm torque. Normally, the accelerometer will become difficult to hold in the fingers for torque greater than 1 $lb_f \cdot in$.

5. MAINTENANCE

An intermittent or permanently open circuit in the accelerometer may be caused by insulating particles or dirt on the tip of the cable. Carefully remove the cable from the accelerometer, wipe the cable tip with a lint-free material (Kimwipe) and replace cable. If trouble persists, place the accelerometer in its shipping box and return to Endevco for repair, with transportation charges prepaid. If the defect is not within the scope of warranty included with this manual, a statement of repair charges and a request for authorization to proceed with repair will be submitted. Address all correspondence and shipment to: Service Engineering Department, Endevco, Rancho Viejo Road, San Juan Capistrano, CA 92675.

INSTRUCTION MANUAL

FOR ENDEVCO®
PIEZOELECTRIC ACCELEROMETERS

NO. 101

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ENDEVCO® MODEL 2222C
MICROMINIATURE ACCELEROMETER

Very Small Size Extremely Lightweight

The Model 2222C, the third generation follow-on to the field-proven Model 2222, is particularly suited for mounting in confined spaces where extremely small size and minimum mass loading are of paramount importance. It is ideal for applications requiring accurate measurement of vibration of circuit board components, air-frame skins, space frame components, flutter models, and other lightweight structures.

The Model 2222C features relatively high charge sensitivity, low transverse sensitivity, broad frequency response, and a wide operating temperature range. The unique replaceable cable interface of the Model 2222C minimizes spurious effects of cable strain and permits rapid replacement of damaged cables.

The Model 2222C is designed for adhesive mounting to the specimen structure. A hard anodized mounting pad provides electrical isolation from the specimen to eliminate spurious ground loop signals. It is a self-generating shear type piezoelectric transducer and requires no external power for operation.

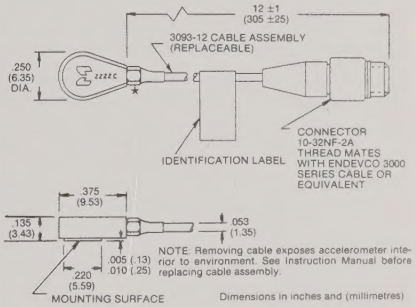
SPECIFICATIONS

(All values are typical at +75°F [+24°C], referenced at 100 Hz and conform to ISA-RP 37.2 [1-64] unless otherwise specified.)

DYNAMIC		
CHARGE SENSITIVITY[1]		
Typical	pC/g	1.4
Minimum	pC/g	1.0
FREQUENCY RESPONSE		
(±5% from typical curve)	Hz	20 to 8000
MOUNTED RESONANT FREQUENCY	kHz	32[2]
TRANSVERSE SENSITIVITY (maximum)	%	5 (3 on special order)
AMPLITUDE LINEARITY[3]		
(approximate sensitivity increase)	%	1.0 per 200 g, 0 to 2000 g
ELECTRICAL		
TRANSDUCER CAPACITANCE	pF	470
TRANSDUCER RESISTANCE		
At room temperature	MΩ	20 000, minimum
At max. operating temperature	MΩ	5000, minimum
GROUNDING		Signal return connected to case. Case insulated from mounting surface by 1 MΩ minimum[4] at 100 Vdc
PHYSICAL		
SENSING ELEMENT	PIEZITE®	Type P-8 in a shear design
WEIGHT	oz (gm)	0.018 (0.5)
CASE MATERIAL		Aluminum
CONNECTOR		Special connector mates with receptacle on one end of supplied cable. Coaxial 10-32 female receptacle at other end of 12-inch cable mates with Endevco 3000 Series coaxial cable.
MOUNTING		Adhesive
ENVIRONMENTAL		
ACCELERATION LIMITS (in any direction)		
Vibration (sinusoidal)	g	1000
Shock	g	10 000
TEMPERATURE RANGE	°F (°C)	−100 to +350 (−73 to +177)
BASE STRAIN SENSITIVITY		
(at 250 μstrain)	EQ g	10.0
HUMIDITY		Sealed by silicone compound

CALIBRATION DATA SUPPLIED

FREQUENCY RESPONSE RANGE	% plot 20 - 8000 Hz, dB plot through resonance
SENSITIVITY (at 100 Hz and 10 g pk)	Pc/g
MAXIMUM TRANSVERSE SENSITIVITY	% of calibrated sensitivity
MOUNTED RESONANT FREQUENCY	kHz
CAPACITANCE (at 100 Hz)	pF



NOTES

[1]Use Endevco Model 2640, 2680 or 2700 Series Charge Amplifiers.

[2]In shock measurements, minimum pulse duration for half-sine or triangular pulses should exceed 0.17 ms to avoid excessive high frequency ringing. (See Endevco Piezoelectric Accelerometer Manual.)

[3]Shocks in the range of 500 to 2000 g may result in temporary zero shifts of up to 4%. Such shifts will result in erroneous data if the accelerometer is used in integrating circuits to obtain velocity or displacement information.

[4]Signal ground to mounting surface, depending on adhesive used.

ACCESSORIES INCLUDED

Model 3093-12 Low Noise Coaxial Cable Assembly, 10-32 female receptacle, 12 in (0.3 m).

Model 2943B Accelerometer Removal Tool.

Model 16205 Cable Removal Tool.

ACCESSORIES OPTIONAL

Model 3060A and Model 3090C Low Noise Extension Cable Assemblies.

Model 3095A Coaxial Cable Assembly, 10-32 plug.

Model 2961 Triaxial Mounting Block.

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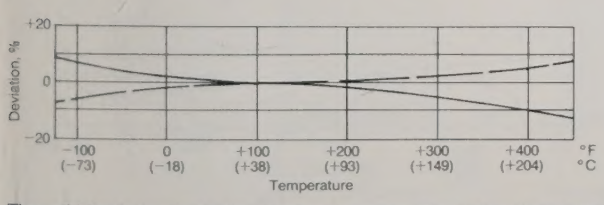
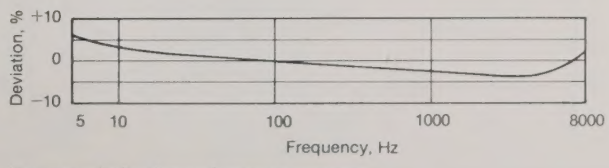
REVERSE SIDE: 2220C

TYPICAL TEMPERATURE RESPONSE



The solid line is the charge-temperature response. The broken line shows the voltage-temperature response with 12-inch cable and 300 pF of external capacitance.

TYPICAL FREQUENCY RESPONSE



The curve is the charge-frequency response.

Continued product improvement necessitates that Endevco reserve the right to modify these specifications without notice.
Endevco maintains a program of constant surveillance over all products to ensure a high level of reliability. This program includes attention to reliability factors during product design, the support of stringent Quality Control requirements, and compulsory corrective action procedures. These measures, together with conservative specifications have made the name Endevco synonymous with reliability.

ENDEVCO

World Headquarters: 30700 Rancho Viejo Road San Juan Capistrano, CA 92675 USA (714) 493-8181 Telex: 68-5608 TWX: 910-596-1415

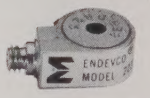
ENDEVCO® MODEL 2220C
MINIATURE RING-SHAPED ACCELEROMETER

Flat Charge-Temperature Response High Frequency Low Mass

PIEZOELECTRIC ACCELEROMETERS

The ENDEVCO Model 2220C Miniature Accelerometer provides proven performance in a wide range of applications and environments. In addition to its small size, light weight, and high resonant frequency, the Model 2220C offers flat charge response over a wide temperature range which makes it ideally suited for use with airborne and laboratory charge amplifiers when exposed to temperature extremes. The center mounting hole makes possible 360° positioning of connector and cable. This feature, in addition to its light weight, makes the Model 2220C especially well-suited to the dynamic testing of small components, light structures, and test specimens that have mounting space limitations.

The Model 2220C is a self-generating piezoelectric transducer and requires no external power for operation.



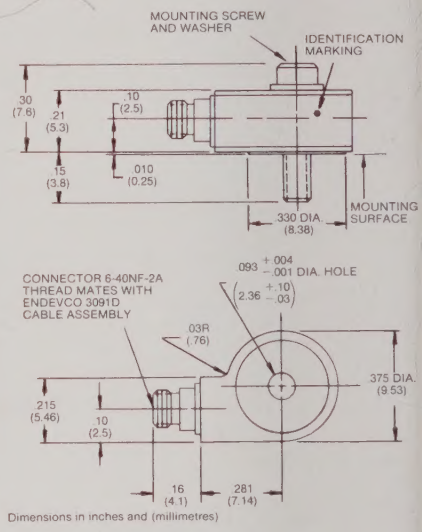
SPECIFICATIONS

(All values are typical at +75°F [+24°C], referenced at 100 Hz and conform to ISA-RP 37.2 [1-64] unless otherwise specified.)

DYNAMIC		
CHARGE SENSITIVITY		
Typical	pC/g	2.7
Minimum	pC/g	2.2
FREQUENCY RESPONSE[1]		
(±5% max, ref 100 Hz)	Hz	20 to 10 000
MOUNTED RESONANT FREQUENCY	kHz	50[2]
TRANSVERSE SENSITIVITY (maximum)	%	5 (2 on special order)
AMPLITUDE LINEARITY		
(approximate sensitivity increase)	%	1.0 per 500 g, 0 to 5000 g
ELECTRICAL		
TRANSDUCER CAPACITANCE	pF	750
TRANSDUCER RESISTANCE		
At room temperature	MΩ	20 000, minimum
At max. operating temperature	MΩ	5000, minimum
GROUNDING		Signal return connected to case
PHYSICAL		
SENSING ELEMENT	PIEZITE®	Type P-8 in a shear design
WEIGHT	oz (gm)	0.08 (2.3)
CASE MATERIAL		Nickel-plated aluminum alloy
CONNECTOR		Coaxial, 6-40 thread
MOUNTING/TORQUE		Hole for accessory mounting screw. 5 lbf-in (0.57 Nm), recommended
ENVIRONMENTAL		
ACCELERATION LIMITS (in any direction)		
Vibration (sinusoidal)	g	1000
Shock	g	5000
TEMPERATURE RANGE	°F (°C)	−65 to +350 (−54 to +177)
BASE STRAIN SENSITIVITY		
(at 250 μstrain)	EQ g	13.0
HUMIDITY		Sealed by epoxy

CALIBRATION DATA SUPPLIED

FREQUENCY RESPONSE RANGE	% plot 20 - 10 000 Hz, dB plot 10 000 - 50 000 Hz
SENSITIVITY (at 100 Hz and 10 g pk)	Pc/g
MAXIMUM TRANSVERSE SENSITIVITY	% of calibrated sensitivity
MOUNTED RESONANT FREQUENCY	kHz
CAPACITANCE (at 100 Hz)	pF



Dimensions in inches and (millimetres)

NOTES

[1]Use Endevco Model 2640, 2680, or 2700 Series Charge Amplifiers.

[2]In shock measurements, minimum pulse duration for half-sine or triangular pulses should exceed 0.10 ms to avoid excessive high frequency ringing. (See Endevco Piezoelectric Accelerometer Manual.)

ACCESSORIES INCLUDED

Model 3091D-120 Low Noise Cable Assembly, 10 ft (3 m) 320 pF, typical.

Model EH96 Mounting Screw 2-56 × ⅜ and washer.

Model EHM178 Hex Wrench.

ACCESSORIES OPTIONAL

Model 12746 Insulated Mounting Screw.

Model 3090C Low Noise Extension Cable Assemblies.

Model EJ34 Adapter (10-32) to join cable assemblies.

U.S. Patent Nos. 3 104 334 and 3 307 054 apply to this transducer.

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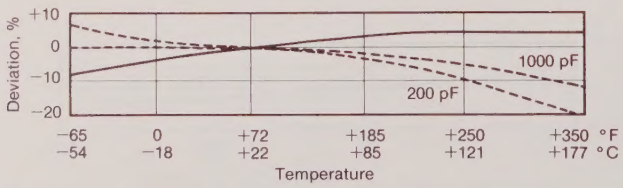
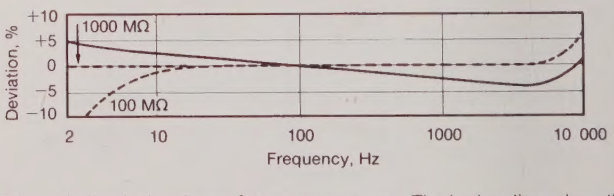
THIS SIDE: 2220C
REVERSE SIDE: 2222C

TYPICAL TEMPERATURE RESPONSE



The solid line is the charge-temperature response. The broken lines show the voltage-temperature response with the indicated external capacitances.

TYPICAL FREQUENCY RESPONSE



The solid line is the charge-frequency response. The broken lines show the voltage-frequency response with 200 pF of external capacitance and the indicated loads.

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Endevco maintains a program of constant surveillance over all products to ensure a high level of reliability. This program includes attention to reliability factors during product design, the support of stringent Quality Control requirements, and compulsory corrective action procedures. These measures, together with conservative specifications have made the name Endevco synonymous with reliability.

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PIEZOELECTRIC ACCELEROMETER INSTRUCTION MANUAL

1.0 ACCELERATION TRANSDUCERS

A piezoelectric accelerometer is an instrument used to measure shock and vibration. It can be idealized by a mass element connected to the case by a spring and a damping medium. The transducing element produces an electrical output proportional to the displacement of the mass element relative to the case and also proportional to the acceleration applied to the case. Most accelerometers can be represented as a single-degree-of-freedom system and are sensitive only in one axis.

The sensitivity of an accelerometer is the ratio of its electrical output to applied acceleration, usually expressed as picocoulombs/g or millivolts/g. It is constant at all frequencies up to approximately one-fifth the resonance frequency.

1.1 Piezoelectric Materials

A piezoelectric material is one which generates an electrical charge when subjected to a mechanical stress or deformation. As a self-generating sensing material, it usually produces a large output for its size and is useful to extremely high frequencies. Rochelle salt, tourmaline, and quartz are examples of "natural" or single crystal piezoelectric materials used in some applications.

Ferroelectric substances can be made to exhibit piezoelectricity by a process of artificial polarization. These polycrystalline ceramics include barium titanate, lead zirconate, lead titanate, and lead metaniobate. The great importance of the ferroelectric materials is that their piezoelectric properties can be controlled in the manufacturing process to produce the characteristics necessary to make a good accelerometer. For this reason ferroelectric ceramics are used in most piezoelectric accelerometers.

1.2 Accelerometer Design

Several designs of accelerometers manufactured by Endevco are illustrated in Figure 1. Inertial mass is identified with the letter M, and the ceramic crystal – shown between mass and support and acting as a stiff spring – by the letter K. The letter K with various subscripts also identifies case walls or other members which act as springs in the accelerometer.

Compression Design

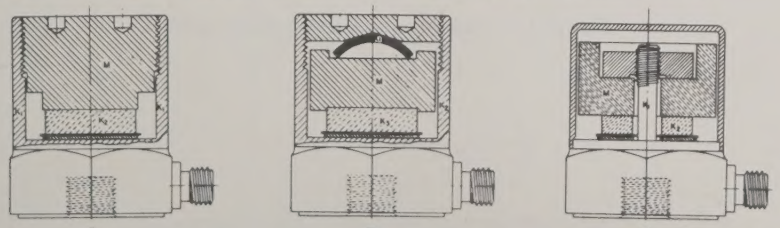
Compression designs provide higher sensitivities for a given resonant frequency than other designs. The simplest design is straight compression, shown in Figure 1A. The ceramic element, K2, rests on an insulated pad to keep the lower electrode insulated from the case. The other electrode is tied to case potential through its contact with the threaded cap or mass. As the transducer is subjected to motion in the positive vertical direction, the compressive stress in the ceramic is increased by inertial forces acting on the mass. A negative motion decreases the compressive stress. Although the ceramic itself provides most of the stiffness in the spring-mass system, the walls on the case in this design contribute to the effective stiffness. This means that any force applied to the case will be reflected in the characteristics and operation of the accelerometer.

Isolated Compression

Improved performance is achieved in the isolated compression accelerometer, Figure 1B. In this design, the basic spring-mass system is isolated from the case by insertion of a second "softer" spring. Although a vast improvement over design 1A, even design 1B does not provide perfect isolation from case effects.

Single-Ended Compression

In compression accelerometers, a high degree of isolation from extraneous effects is achieved in the Endevco® single-ended compression design (Figure 1C). Its basic components are a base, a center post, a cylindrical ceramic element and mass, and a compression member. The cap, which simply covers the completed assembly and is welded to the base, acts only as a protective cover and is not in direct contact with the spring-mass system.



A
STRAIGHT COMPRESSION

B
ISOLATED COMPRESSION

C
SINGLE – ENDED COMPRESSION

Figure 1. Accelerometer Designs

Shear Design

In the Endevco® shear design, U.S. Patent No.'s 3,104,334, 3,104,335 and 3,307,054 (Figure 1D) a hollow cylinder of ceramic material is bonded to a center post. A concentric hollow cylindrical mass is then bonded to the crystal. When the unit is subjected to an acceleration along the axis of the post, the entire cylinder of crystal is subject to a shear stress.

This design has several unique advantages. As in single-ended compression design, the case acts only as a protective cover and is not in contact with the spring-mass system. Also, if the center post is made hollow and extended through the case, the resulting accelerometer can be mounted by simply passing an ordinary machine screw through the hole to attach it to the test structure. Another major advantage of the shear approach is that it can quite successfully be built with extremely small dimensions. The majority of light weight microminiature accelerometers from Endevco are shear units.

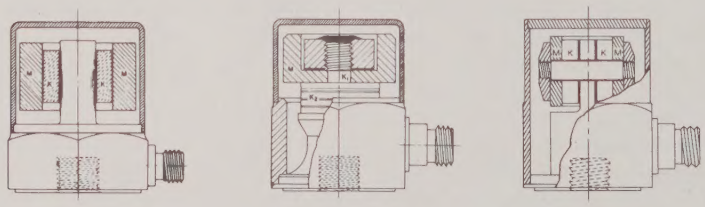
ISOBASE® Design

The ISOBASE® design is essentially identical to the structure of single-ended compression accelerometers except that the sensing element is mounted on a pedestal (Figure 1E). It provides a high degree of isolation of the sensing elements from forces on the case. Error signals caused by bending stresses in the mounting surface of an ISOBASE® accelerometer are reduced by a factor of 20 to 40 when compared to other compression accelerometers.

ISOSHEAR Design

The ISOSHEAR combines the advantages of the ISOBASE® design with a flat plate bolted shear design to provide the highest degree of isolation of the sensing elements from forces on the case. In this design (Figure 1F) a balanced beam configuration is used, consisting of two separate masses (M) and two separate crystal stacks (K) bolted together to form a single unit. The bolt is not connected with the center post so does not contribute to the spring constant. The crystal stack generates output signal only when subjected to a shear stress (i.e., along the vertical axis).

The base design minimizes the amount of stress experienced by the center post. The crystal stack, polarized in the shear mode is almost totally insensitive to stress in the post. This is true whether the initial case distortion is caused by base stress, accoustical pressure or thermal shock.



D
SHEAR

E
ISOBASE®

F
ISOSHEAR™

Figure 1. Accelerometer Designs (continued)

2.0 PIEZOELECTRIC ACCELEROMETER CHARACTERISTICS

2.1 Equivalent Circuits

The equivalent circuit for a piezoelectric transducer is shown in Figure 2. In practice, the internal resistance, R_S shown in circuit (2A) normally exceeds 20,000 megohms and, thus, can be ignored when considering the over-all transducer performance. Similarly, effects due to the internal inductance are not significant until far beyond the upper frequency limit of the transducer and can also be ignored. The simplified circuit (Fig. 2B) is adequate for applications analysis.

The piezoelectric transducer is effectively a capacitor which produces a charge, q, across its plates proportional to a force applied to the crystal. The open circuit voltage, e, out of the transducer is equal to the generated charge divided by the transducer capacitance, or $e\ (\text{volts}) = \frac{q\ (\text{picocoulombs})}{C_p\ (\text{picofarads})}$. Thus, the transducer can also be represented as a voltage generator and a series capacitance (Fig. 2C).

2.2 Sensitivity

The sensitivity of an accelerometer is defined as the ratio of its electrical output to its mechanical input. It may be expressed in units of charge per unit of acceleration or voltage per unit of acceleration. It is important to note the terms in which the respective parameters are expressed: e.g. average, rms, or peak.

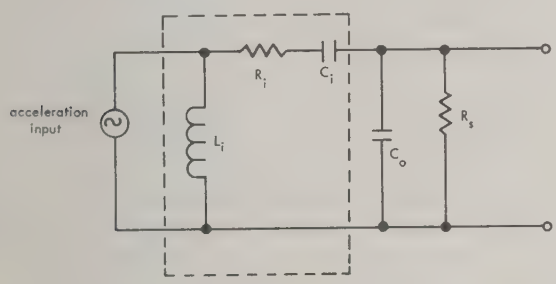
Charge Sensitivity

Each Endevco® accelerometer is provided with a charge sensitivity calibration, Q, expressed in picocoulombs per g (pC/g). This is measured directly or derived from Q = EC, where Q is expressed in picocoulombs, E in Volts, and C in picofarads. This calibration is used when the accelerometer is operating into charge measuring electronics. Note that magnitude of sensitivity can be expressed in other terms:

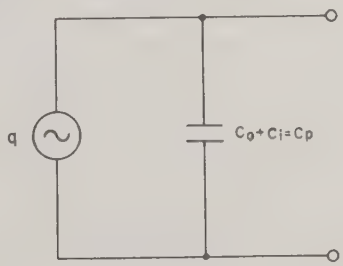
$$\frac{pC}{g} = \frac{\text{rms pC}}{\text{rms g}} = \frac{\text{pk pC}}{\text{pk g}} = 1.41\ \frac{\text{rms pC}}{\text{pk g}}$$

Voltage Sensitivity

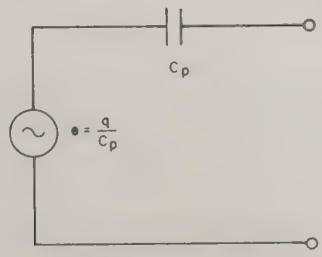
Most calibration cards also carry the accelerometer voltage sensitivity, E, in millivolts per g (mV/g) as calculated with a stated amount of external capacitance connected to the accelerometer. When observing the signal level on an rms voltmeter, use the value 0.707 x E(pk mV/pk g). Use 2 x E as the accelerometer sensitivity when measuring peak-to-peak voltages with a galvanometer recorder or oscilloscope.



A
EQUIVALENT CIRCUIT



B
SIMPLIFIED CHARGE GENERATOR EQUIVALENT



C
SIMPLIFIED VOLTAGE GENERATOR EQUIVALENT

Figure 2. Equivalent circuits for a piezoelectric transducer (A) actual circuit, (B) charge generator equivalent, and (C) voltage generator equivalent.

Effect of Cables on Sensitivity

When performing measurements, the transducer circuit involves an external capacitance and a shunt resistance. The external capacitance C_t is commonly cable capacitance plus input capacitance of the associated amplifier. The shunt resistance R_i is commonly the input resistance of the associated amplifier (Figure 3).

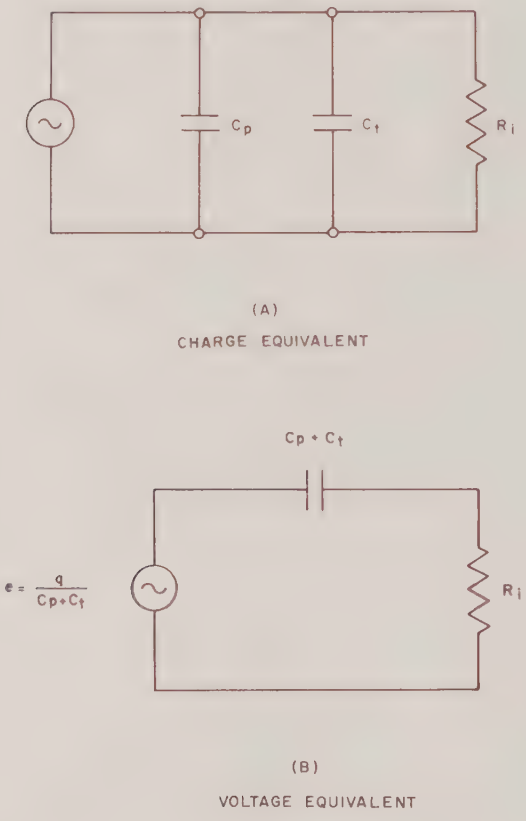


Figure 3. Equivalent circuits for a normal piezoelectric transducer system: (A) charge equivalent, and (B) voltage equivalent.

Since the charge generated does not change, regardless of the amount of external capacitance added, the charge sensitivity of the accelerometer remains unaffected by the length of interconnecting cable. This characteristic explains the practical advantage of a system incorporating charge measuring electronics rather than voltage amplifiers.

When using voltage amplifiers, the amount of external capacitance must be considered in establishing the signal at the input of the amplifier. With added capacitance, the output voltage (appearing across R_i) becomes:

$$e = \frac{q}{C_p + C_t}$$

The total system capacitance during actual use may differ from the capacitance that was used in the original calibration. This changes the basic voltage sensitivity up or down by a calculable amount. The new sensitivity can be determined with either of two equations:

$$E = \frac{Q}{C_p + C_t} \times 1000 \qquad (1)$$

Where:

E = new sensitivity being determined, in millivolts per g (mV/g)

Q = factory supplied charge sensitivity, in picocoulombs per g (pC/g)

C_p = transducer internal capacitance, in picofarads (pF)

C_t = total capacitance external to the transducer for which E is being established, in picofarads (pF).

For example:

Q = 34.7 pC/g

C_p = 575 pF

C_t = C_{cable} (200 pF) + C_{ampl} (25 pF)

= 225 pF

$$E = \frac{34.7 \times 10^{-12}}{(575 + 225)10^{-12}} = \frac{34.7}{800} = .0434 \text{ Volts/g}$$

E = 43.4 mV/g = 43.4 mV pk/g pk

= 30.7 mV rms/g pk

Another form of Equation 1 can be written as:

$$E = E_{cal} \frac{C_p + C_{cal}}{C_p + C_t} \qquad (2)$$

Where:

E = new sensitivity being determined, in mV/g.

E_{cal} = factory supplied voltage sensitivity, in mV/g.

C_p = transducer internal capacitance, in pF.

C_{cal} = external capacitance used when calibrated at factory, in pF.

C_t = total capacitance external to the transducer for which E is being established, in picofarads (pF).

For example:

E_{cal} = 51.4 mV/g

C_p = 575 pF.

C_{cal} = 100 pF.

C_t = C_{cable} (200 pF) + C_{ampl} (25 pF).

= 225 pF.

$$E = 51.4 \frac{575 + 100}{575 + 225} = 51.4 \frac{675}{800} = 43.4$$

E = 43.4 mV/g.

Note: (a) The values of Q, Cp, E_{cal} and C_{cal} will be found on the individual calibration cards shipped with each transducer.

(b) The input capacitance of many voltage amplifiers is approximately 25 pF. Consult individual amplifier data sheets.

(c) E and E_{cal} may be expressed as either mV rms/g pk or mV pk/g pk, where: mV/g = mV rms/g rms = mV pk/g pk and mV rms/g pk = 0.707 mV/g.

Standardization — Voltage Sensitivity

The effect of added shunt capacitance on voltage sensitivity can be used to advantage in standardizing accelerometer output to a desired value.

Shielded capacitors can be used to standardize the sensitivity of any accelerometer to any value E less than its original calibration E_{cal} such as 10 rms mV/pk g, so that g levels instead of millivolts can be read directly from the scale of a vacuum tube voltmeter without interpolation. In other instances where very high g levels are expected, it may be necessary to reduce the sensitivity of the accelerometer by a factor of 10 or more in order not to exceed the 5 volt output limit of most voltage amplifiers. To arrive at the exact capacitance to be added to an accelerometer for a desired value of E, use Equation 1 above in this new form:

$$C_t = \frac{1000\ Q}{E} - C_p \qquad (3)$$

For example:

E = 10 pk mV/pk g (desired value)

Q = 34.7 pk pC/pk g

C_p = 575 pF

$$C_t = \frac{34.7 \times 10^{-12}}{10 \times 10^{-3}} - 575 \times 10^{-12}$$

$$= (3470 - 575) \times 10^{-12}$$

C_t = 2895 pF.

Alternatively, we may use a new form of Equation 2:

$$C_t = \frac{E_{cal}}{E}(C_p + C_{cal}) - C_p \qquad (4)$$

For example:

E = 10 pk mV/pk g (desired value)

E_{cal} = 51.4 pk mV/pk g

C_p = 575 pF

C_{cal} = 100 pF

$$C_t = \frac{51.4}{10}(575 + 100) - 575$$

$$= 5.14(675) - 575$$

C_t = 2895 pF

Standardization — Charge Sensitivity

Although adding shunt capacitance has no effect, addition of *series* capacitance will reduce the effective transducer charge output. See Figure 4. The charge which appears at the charge amplifier input is:

$$Q_{amp} = Q \frac{C_s}{C_p + C_i + C_s} \qquad (5)$$

Where:

Q = basic transducer charge sensitivity, in pC/g.

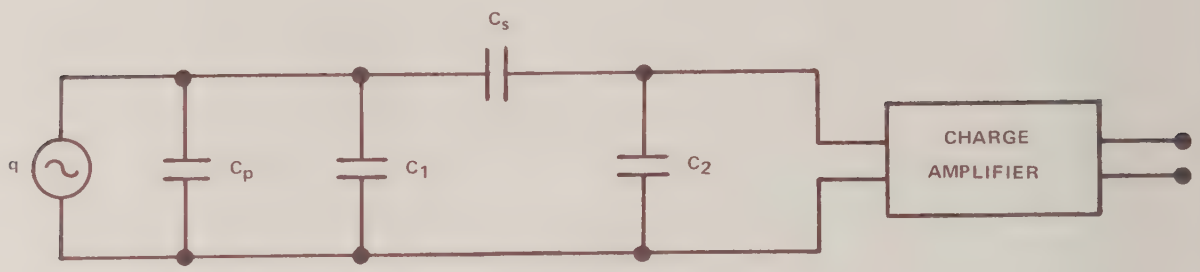


Figure 4. Series swamping equivalent circuit - for reducing transducer charge output.

C_p = transducer internal capacitance, pF.

C_1 = external parallel capacitance *ahead* of series capacitor, pF.

C_s = series swamping capacitance, pF.

C_2 = external parallel capacitance *beyond* the series capacitor, pF.

Note that although C_2 is, in general, present, it has no effect on system charge sensitivity.

2.3 Polarity

For many shock and vibration measurements it is necessary to know the polarity of the system output relative to the direction of motion of the transducer. To determine this the polarity of the accelerometer output and the input-output phase relationship of the amplifier must be known.

Unless otherwise specified, all Endevco® accelerometers produce a positive output signal when the transducer is oriented with its base down and the direction of acceleration is upwards. The force on the accelerometer is into the base.

2.4 Frequency Response

Low Frequency Response

A piezoelectric accelerometer is a *self-generating* transducer that produces an electrical output signal that is porportional to acceleration, without the use of an external power source or carrier voltage. In practice, such a transducer cannot be used to measure constant or steady-state accelerations. At zero frequency no mechanical energy is being put into the system, thus electrical energy cannot be continuously removed.

When using charge amplifiers the system low frequency response is determined primarily by the low frequency response of the amplifier. The length of cable between transducer and amplifier will not affect the low frequency of the system, which is limited only by the characteristics of the amplifier.

When using voltage amplifiers, the low frequency response of a piezoelectric accelerometer is a function of the RC time constant of the accelerometer and the input resistance of the matching electronics. For instance, the Model 2220C or other Piezite® Element Type P-8 accelerometer, with an internal capacitance of approximately 750 pF and used with a 200 pF cable, requires a high input resistance (100 MΩ or better) to work into a voltage amplifier and provide satisfactory frequency response to 5 Hz. However, the Model 2215E Accelerometer, with a capacitance of approximately 10,000 pF, will work directly into a voltmeter or other device with an input impedance of 2 to 10 MΩ and still provide good low frequency response.

Of course, the low frequency response of any accelerometer can be improved by swamping with additional shunt capacitance, such as long cables, to raise the RC time constant. However, this technique will also affect sensitivity as discussed on the preceding pages.

Actual response at any frequency can be measured from Figure 5.

Where:

f = frequency in Hz

R = input resistance of the matching amplifier in ohms

C = total capacitance in farads of the accelerometer, plus additional applied shunt capacitance, if any

Example:

If the frequency (f) of desired measurements is 10 Hz, total capacitance (C) of accelerometer and cable is 500 pF, and amplifier input impedance (R) is 100 MΩ (Endevco® cathode follower), we can determine:

$f \times R \times C = 10 \times 100 \times 10^6 \times 500 \times 10^{-12} = 0.50$

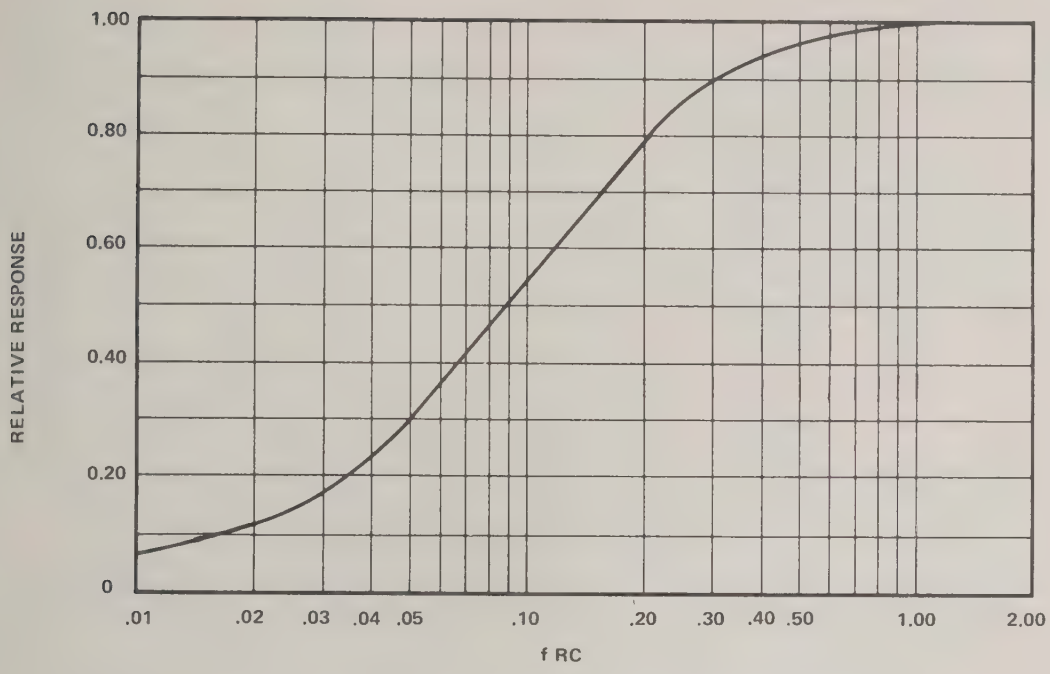


Figure 5. Low Frequency response vs. loading (voltage amplifiers).

Using Figure 5, we find that the relative response corresponding the fRC = 0.5 is 95%, indicating that the signal at 10 Hz will be down approximately 5%.

Using the same formula in the case of a Model 2215E Accelerometer with an approximate capacitance of 9,500 pF we can see that for frequency response to 10 Hz and 10 MΩ input impedance, we obtain:

$$f \times R \times C = 10 \times 10 \times 10^{6} \times 9{,}500 \times 10^{-12} = 0.95$$

Again using Figure 5, the relative response is approximately 99%. Thus, a 10 Hz signal will be down approximately 1%.

High Frequency Response

High frequency response of a piezoelectric accelerometer is a function of its mechanical characteristics. A piezoelectric accelerometer can be represented as an undamped single-degree-of-freedom spring-mass system, the response of which is shown in Figure 6 as a function of frequency.

For the accelerometer, this curve can be considered as showing the variation in sensitivity of the transducer with frequency. The response curve shows that at 1/5 the resonance frequency, the response of the system is 1.04. This means that the sensitivity of the accelerometer is 4% higher at that frequency than at the lower frequencies. Since 5% is the maximum error that most users permit, the "flat" accelerometer frequency range should be considered limited to 1/5 the resonance frequency. Data can, of course, be obtained for frequencies *above* 1/5 the resonance frequency, as long as appropriate correction factors are applied to compensate for the "resonant rise".

Resonance Frequency

The American National Standards Institute defines resonance frequency as that frequency at which the sensitivity of the pickup is a maximum (ANSI S2.2 - 1959 Section 2.13). Several methods can be used to determine accelerometer resonance frequency. Unfortunately, they do not all give the same answer. To evaluate these various methods, resonance frequency determinations were made for an Endevco® Model 2224C, using these techniques.

First, assuming the accelerometer to be an undamped spring-mass system, the resonance frequency was *computed* using the following equation:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Using only the values for crystal spring constant and inertial mass, the *calculated* resonance was 91 kHz.

Next, the accelerometer was connected in series with a resistor to a variable frequency oscillator. A vacuum tube voltmeter connected across the accelerometer measured variations of transducer impedance as the oscillator frequency was varied over its range. Resonance frequency determined by this method was 49 kHz.

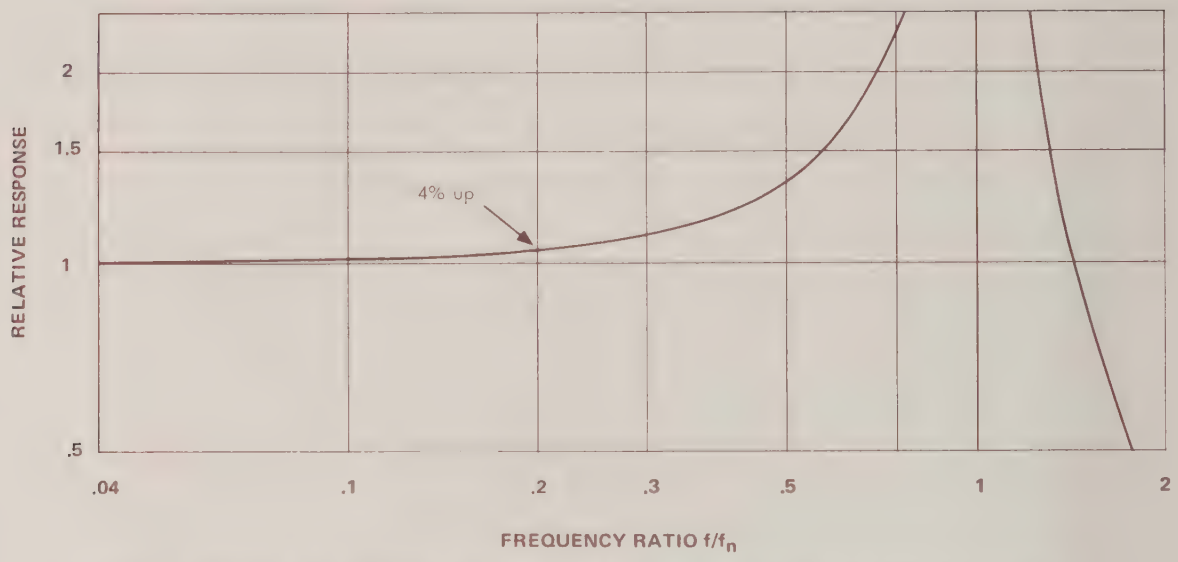


Figure 6. Response of an undamped single-degree-of-freedom spring-mass transducer when the case is undergoing sinusoidal acceleration.

Using a special ballistic drop ball shock machine developed by Endevco, the *unmounted* accelerometer was subjected to a half-sine mechanical shock of approximately 2,500 g with a time duration of 70 μsec. The resultant ring frequency indicated a resonance of 50 kHz.

The accelerometer was then mounted on a 1" long, 3/4" diameter steel anvil and again subjected to the 2,500 g shock in the drop ball machine. The response in this case indicated a resonance frequency of 35 kHz.

Finally, the accelerometer was mounted on a special high frequency shaker whose own resonance frequency is above 50 kHz and whose built-in reference accelerometer had been previously calibrated. The comparison calibration showed a mounted resonant frequency of 32 kHz for the 2224C.

The test results are shown in Table 1.

Table 1.

Results of Several Techniques
of Resonance Frequency Determinations
For a Model 2224C Accelerometer

Test Method	Resonance Frequency	Indicates "Flat" To
Calculated	91 kHz	18.2 kHz
Electrical	49 kHz	9.8 kHz
Unmounted Shock	50 kHz	10 kHz
Mounted Shock	35 kHz	7 kHz
Mounted Vibration	32 kHz	6.4 kHz

This accelerometer is rated (quite conservatively) as having a resonance frequency of 32 kHz "nominal." Models with higher mounted resonance frequencies are available; the Endevco® Model 2292 Shock Accelerometer, for instance, is rated at 125 kHz.

Accelerometers should be selected with resonance frequencies at least 5 times higher than the highest frequency of interest (or with a natural period less than 1/5 of an input shock pulse duration). To be valid, however, the resonance frequency specified *must* be mounted mechanical resonance. Since the accelerometer will be mounted in use, the mounted resonance is the only one of value to the user.

2.5 Strain Sensitivity

Strain Sensitivity or base bending sensitivity is defined as the spurious output from an accelerometer caused by strains imposed in its base by the deformation of the specimen to which it is attached. At Endevco, strain sensitivity is expressed in equivalent g at a strain of 250 microinches per inch. This is the level recommended by the American National Standards Institute for measuring strain sensitivity (ANSI S2.11-1969 Para. 8.5).

Many years of testing at Endevco have shown that piezoelectric accelerometer strain sensitivity is not a linear function of specimen strain. Therefore, data obtained at 250 microstrain should not be linearly extrapolated for values less than or above 250 microstrain. For precise data at strain values other than 250 microstrain, tests should be conducted at the strain value of interest by the procedures recommended in ANSI and ISA Standards.

Application Notes

In most applications, a strain may be known to exist in the specimen under an accelerometer. However, the actual magnitude of the strain may not be known. Thus, if the structure under an accelerometer is expected to bend or strain during a measurement, the accelerometer should be selected for minimum strain sensitivity. The strain sensitivity of an accelerometer can be significantly reduced by mounting it on an insulated stud or a stud with a thick flange.

Shear type accelerometers tend to be less susceptible to strain than compression types. The sensing element is not physically in intimate contact with the base, and base deformations can be transmitted to the crystal only through the crystal mounting post. The crystal of the normal compression unit, however, is subjected to the direct bending mode of the base.

To broaden the utility of the compression type accelerometer by reducing its susceptibility to base bending effects, Endevco engineers developed the ISOBASE® series of accelerometers. Bending relief has been incorporated in the transducer mechanical design to isolate the base bending deformations from the compression sensing system. Base bending sensitivities equal to, and lower than, those of typical shear designs are available in the ISOBASE® type compression accelerometers.

Endevco®s recently introduced ISOSHEAR accelerometers now provide the lowest sensitivity to strain. By combining the shear design with a strain isolating central mounting post, the effects of strain, including thermally induced strain, are almost totally eliminated.

2.6 Dynamic Range and Linearity

The range of input acceleration levels for which accelerometer sensitivity remains constant is defined as the range of "Amplitude Linearity." Although a piezoelectric accelerometer is theoretically linear down to 0 "g", a practical lower limitation is imposed by the noise level of impedance matching electronics. For very low vibration levels, high output accelerometers such as the Endevco® ISOSHEAR Series are required. For example, the 1 000 pC/g 7705-1000 operating into a low-noise amplifier (Model 2735) can provide a broadband noise floor of 25 μg or less.

Upper limits of linearity may be imposed by either non-linear response of the piezoelectric element or by fragility of the transducer as a whole. In either case, the limits can be accurately determined only through actual evaluation. The sensitivity of piezoelectric accelerometers increases with acceleration level. At Endevco, Amplitude Linearity is expressed as the g level at which the sensitivity increases 1%. The maximum recommended or measureable acceleration level is also specified.

In addition to linearity specifications, Endevco accelerometers are also given an "environmental" rating of maximum allowable vibration and shock input. These environmental ratings are conservative and are generally well below the actual damage limits of the transducer.

2.7 Phase Shift

In an accelerometer, phase shift is defined as the time delay between the mechanical input and the resulting electrical output signal. All vibration encountered in practice is complex, and like shock, is composed of a number of frequencies superimposed in a specific way. If transducer phase shift is not linear with frequency, the various frequency components will be shifted relative to one another and the resultant electrical output will be a distortion of the mechanical input.

To avoid distortion, transducer phase shift (over the useful frequency range) must be either constant (0° or 180°) or linear with frequency. The piezoelectric accelerometer, with virtually no damping, has 0° phase shift to near its resonance frequency, well beyond its rated frequency range. With some accelerometers linear phase shift can be attained with a damping ratio of 0.707, however, damping usually varies with temperature, resulting in distortion for any but room temperature use.

2.8 Transverse Sensitivity

For any piezoelectric accelerometer there exists one axis which provides maximum response for an input acceleration. The charge output along this axis for a 1 g input is Q_{max}, the maximum sensitivity. The sensitivity, Q_θ, along any other axis (inclined at an angle θ from the axis of Q_{max}) is $Q_{max} \cos \theta$. In a perfect transducer, the vertical axis (y axis in Fig. 7) and the axis of Q_{max} would coincide. In practical accelerometers, due to manufacturing tolerances and crystal element variations, they do not.

As a result, these transducers characteristically exhibit a basic sensitivity of $Q_\theta = Q_{max} \cos \theta$ and a (maximum) transverse output $Q_T = Q_x = Q_{max} \sin \theta$.

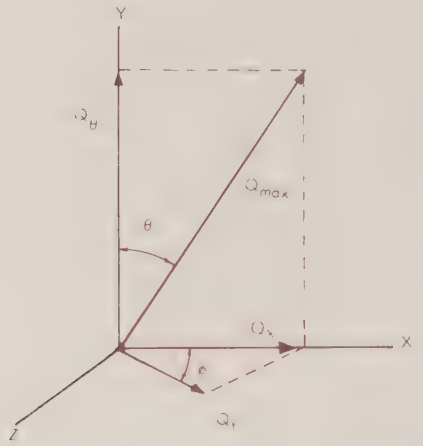


Figure 7. Transverse sensitivity of a piezoelectric accelerometer.

Transverse sensitivity is expressed as a percentage of the basic sensitivity and, thus, is defined as:

$$\text{Maximum Transverse Sensitivity} = \frac{Q_T}{Q_\theta} \times 100 = \tan\theta \times 100\% \qquad (6)$$

For motion in the transverse (XZ) plane along any other axis (inclined at an angle ϕ from the X axis) the transverse sensitivity is $Q_t = Q_T \cos\phi$. Thus, a more general expression becomes:

$$\text{\% Transverse Sensitivity} = \frac{Q_t}{Q_\theta} \times 100 = \tan\theta \cos\phi \times 100 \qquad (7)$$

A typical transverse sensitivity plot is shown in Figure 8.

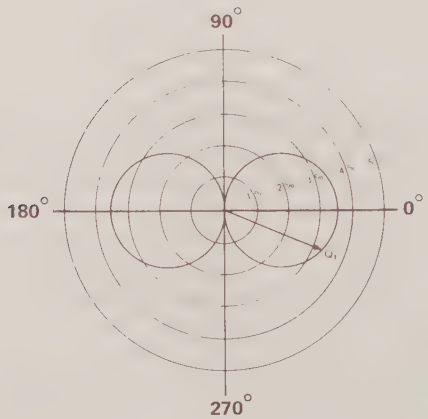


Figure 8. Typical transverse sensitivity plot for a piezoelectric accelerometer.

In most Endevco® accelerometers, Q_t varies from a maximum of 3% to a minimum of nearly zero. Many models are available with a maximum transverse sensitivity of 2% or even 1%. Both single-ended compression and shear designs exhibit excellent transverse sensitivity characteristics. See individual data sheets on specific models.

2.9 Non-Vibration Environments

All Endevco® accelerometers are sealed and tested for case leaks and will operate under normal conditions of humidity, salt spray, sand, dust, and altitude. An epoxy seal has proven satisfactory for most environments. However, if an accelerometer is to be subjected to a humidity qualification test, such as that outlined in MIL-E-5272C, a fusion sealed accelerometer should definitely be used. Most Endevco® accelerometers are available in hermetically sealed versions which will meet these requirements. Whenever a true hermetic seal is specified by Endevco, the unit is sealed either by welding and/or soldering. Experience has shown that while an epoxy seal might survive severe temperature-humidity cycling, there is some probability that moisture will be inbreathed and cause reduced performance. True hermetically sealed piezoelectric accelerometers are unaffected by vacuum and are suitable for deep space applications.

Acoustic Noise

Considerable vibration in flight or static testing is induced by acoustical energy. It has been shown in numerous cases that random acoustical energy at 120 dB can induce vibrations of the order of 50 g's or higher in structural members, and it can be assumed that higher acoustic levels may increase the vibration levels although not necessarily linearly. It has also been shown that crystal accelerometers have, at the most, noise outputs equal to only a fraction of a g at 140 dB noise levels so that if the usual high level vibrations are to be measured in acoustic fields, good signal-to-noise ratios and accuracies are obtainable. There are other cases, however, where low level evaluations on structures that are not subject to acoustic excitation must be made in high level acoustic fields. In these cases considerable attention must be paid to the acoustic response of the measuring system to assure good signal-to-noise levels and accuracies. Resonance frequency (f_n) of the crystal accelerometer must be at least three times the highest acoustic frequency expected.

RF and Magnetic Fields

Magnetic and RF fields have no effect on the Piezite® Element. If an accelerometer includes magnetic materials a spurious output may be observed when it is vibrated in a high magnetic field or subjected to high intensity changing magnetic flux. Adequate isolation must be provided against RF ground-loops

and stray signal pickup. The Model 2986B Insulated Mounting Stud can be used for electrical isolation of the accelerometer from ground. High intensity RF or magnetic fields may require special shielding of the accelerometer, cable, and amplifier.

Temperature

In general, Endevco® accelerometers are rated for three temperature ranges: -65°F to +230°F, -65°F to +350°F, and -320°F to +500°F. In addition, Piezite® Element Type P-10 operates from -452°F to +750°F. Piezite® P-14 operates to +1000°F; and Piezite® P-15, to +1400°F. Within their usable temperature ranges the various crystal materials show variations in sensitivity, capacitance, and resistance. The deviation of voltage output with temperature is almost always different from the charge output deviation. It is important, therefore, when using charge measuring electronics, to select accelerometers with flat charge characteristics; and with voltage equipment, to choose accelerometers with flat voltage response curves.

It was mentioned earlier that when accelerometers are operated into voltage amplifiers, low frequency response is dependent on the accelerometer-amplifier RC time constant. At higher temperatures, the internal resistance of piezoelectric crystals decreases, causing a reduction in the effective RC time constant. Since charge sensing electronics can operate with lower source resistance than voltage amplifiers, charge amplifiers are recommended for use with accelerometers operating at very high temperatures. At the very least, internal resistance as a function of temperature should be measured during calibration so that correction factors can be applied, if necessary.

As the accelerometer temperature is increased beyond its rated operating limit, the crystal begins to depolarize, with a resultant loss of sensitivity. If the unit is exposed to excess temperatures for only a short period, it may still be usable. It must, however, be recalibrated since it will have a new sensitivity of lower value. If the temperature is increased until the crystal reaches its Curie point, the accelerometer will be completely depolarized and unusable.

Transient Temperatures

In addition to the characteristics described above, which are functions of *temperature*, some piezoelectric accelerometers also exhibit an electrical output which is a function of *rate of change of temperature*. These outputs can be quite large and are due primarily to two effects: (1) Thermal transients may cause differential or non-uniform stresses in the accelerometer structure. This results in changing forces on the crystal element which, in turn, produce an electrical output. (2) Some piezoelectric materials exhibit *pyroelectric effect* in which an electrical output occurs as a function of temperature change. Fortunately, these effects are not as serious as might be assumed. The usual pyroelectric output is a quasi-static phenomenon which follows the slow variation in crystal temperature. As a result, the signals generated are generally below the low frequency cutoff of the piezoelectric transducer system and cause no problem.

Certain construction configurations are notably less susceptible to the effects of thermal transients than others. For example, shear types exhibit less response to thermal changes than do compression types, and ISOSHEAR® accelerometers exhibit almost no response. When measuring low frequency shock in the presence of rapid-thermal change, therefore, accelerometers with low sensitivity to thermal shock should be selected.

Even though the temperature around an accelerometer may vary rapidly, there usually is sufficient thermal lag (delay in heat transmission) in most accelerometers that the resultant signal is low frequency in nature and, thus, rejected in the signal conditioner.

In severe environments transient thermal effects may be eliminated or reduced by:

1. Selecting a transducer which is known to have superior transient temperature characteristics (such as ISOSHEAR).
2. Incorporate thermal shielding to increase the thermal lag at the transducer.
3. Ensure that the low frequency response of the system is no better than necessary for the application involved. Insertion of a high pass (5 Hz) filter may even be advisable.

A piezoelectric accelerometer that is subjected to a large change in temperature (heating or cooling) may develop a high electric charge across its sensing element. If the accelerometer is connected to a signal conditioner or other element instrument, this charge will leak off and dissipate itself through the input circuitry. The resultant signal usually is negligibly small. If the accelerometer were open circuited, the high voltage that develops as a result of the charge may cause a loss of sensitivity. It is recommended, therefore, that piezoelectric accelerometers subjected to temperature extremes be either connected to an electronic instrument or shorted with a shorting cap.

Nuclear Radiation

Accelerometers can be exposed to relatively large radiation doses without any harmful effects. Battelle Memorial Institute reports that piezoelectric accelerometers have been exposed to a neutron fluence of 10^{16} n/cm^2 and with gamma radiation up to 10^{11} ergs/g (C). Most of the accelerometers tested operated normally without displaying any effects due to these radiation environments. It has also been reported that piezoelectric ceramics experience no lattice changes at a neutron fluence as high as 10^{18} n/cm^2.

Radiation-hardened accelerometers are available from Endevco. Contact your local Endevco Field Engineer or Representative for latest information.

3.0 APPLICATIONS INFORMATION

3.1 Mounting Techniques

For an accelerometer to generate accurate and useful data, it must be properly coupled to the equipment under investigation. The method of attachment must not introduce any distortion. This requires that the accelerometer mounting be rigid over the frequency range of interest. In practice, many mounting methods are suitable for a wide variety of applications and depend on the practical requirements of the test system. For assistance in unusual situations contact your local Endevco Field Engineer.

Standard Stud Mounting

When possible, the best method is to mount the accelerometer with a stud (Model 2981-3 furnished with most accelerometers) so that the entire base of the accelerometer is in good contact with the test object. Care should be taken to ensure a flush mating with a smooth, flat surface. The mounting hole must be at a right angle to the surface. Ordinary machine screws are to be avoided since without a flange or shoulder, it is possible to "bottom" the screw in the accelerometer, thereby changing its dynamic response and in some cases causing damage to the unit.

Insulated Mounting Studs

Insulated (electrically isolated) mounting studs, available only from Endevco (U.S. Patent 2,972,006), provide isolation of the accelerometer from electrical ground, and they are particularly useful in preventing ground loops. Endevco® insulated mounting studs are well proven and are vastly superior to any means of internal isolation, which does not also eliminate the effect of stray capacitance to ground.

Cementing Studs

A series of cementing studs is available which permits accelerometer attachment to surfaces that cannot be drilled and tapped to accept threaded studs. Use of these studs rather than cementing the transducer directly to the test specimen will prevent contaminating accelerometer mounting threads with adhesive; also, removal of the accelerometer will be facilitated. Adhesives should not be scraped or sanded from accelerometer, since a rough mounting surface can cause poor frequency response and/or an increase in transverse sensitivity.

Suggested cement is Vigor Aron Alpha (Vigor Co., New York, N.Y.). Dental cements such as Grip (L.D. Caulk Company, Milford, DE) are useful when the mounting surface is irregular or when the transducer will be subjected to high humidity or immersion. For semi-permanent or permanent installations, or for use with cement studs, the following adhesives are suggested.

> Transmount HT Adhesive Film (Girder Process, Inc., Carlton Hill, NJ), useful to +400°F; Epon 828 (Shell Chemical Corp., New York, NY); and Epibond 1210 (Furane Plastics, Inc., Los Angeles, CA), which can be cured at room temperature.

Efficiency of these adhesives depends entirely on the material and the curing technique used. Thorough evaluation is recommended for the individual application.

Application Notes

The table below lists the recommended mounting torques for the various sizes of Endevco® mounting studs. To assure repeatable measurements and to prevent damage to the stud by overtorquing, a torque wrench should be used to mount all accelerometers.

Mounting Stud Thread	Recommended Mounting Torque (±10%) in.-lb.	kg-cm	Nm
2-56	5	6	0.6
4-40	8	9	0.9
6-32	10	12	1.1
10-32	18	20	2.0
1/4-28	24	27	2.7
M5 x 0.8mm	18	20	2.0

Poor accelerometer mounting surfaces will result in unreliable data. It is recommended that the mounting surfaces and tapped holes conform to the following specifications. These are considered to be easily achieved by following good machine shop practices:

Surface Flatness	0.0003" TIR
Surface Roughness	$\sqrt{32}$
Perpendicularity of Hole:	± 6 minutes
Tap Class	2

For all studs, the use of a drop of light oil between the mating surfaces is recommended when frequencies are above 5000 Hz or shock pulse durations are short.

If no oil is used, the mechanical connection to the structure may not be rigid enough, and the resonance frequency of the mounted accelerometer may be reduced by 20 to 30%. This means that the rise in response at 10 kHz for an accelerometer with a nominal 35 kHz resonance would be doubled, approximately, without the use of oil. No evidence of an improvement due to the use of oil has been noted below 5 kHz.

Binding, seizing, or galling of a mounting stud within a test fixture's internal thread may cause some difficulty in removing the stud from the fixture. In the case of steel test fixtures, a small amount of lubricating oil may be applied if this appears necessary. To prevent this with aluminum fixtures, the use of a thread lubricating, anti-seizing compound is recommended. This compound should be applied to the internal threads of the test fixture or the external threads of the stud, prior to mounting. It should be in contact with the threads only and not the mounting surface. This will ensure that the compound, which is sometimes gritty, does not adversely affect the high frequency response.

A special caution is called for with the use of insulated mounting studs. If the lubricant used is conductive, it should not be allowed to creep across the insulating layer of the flange.

When an accelerometer is mounted to a structure by means of pressure sensitive tape or an epoxy insulated mounting stud, its effective mounted resonance frequency will be lower (15 to 30%) than the resonance frequency determined with a solid mounting stud. It is recommended that such mounting methods be evaluated, particularly over the range of frequencies to be measured.

Attempts to use a piezoelectric accelerometer as a hand-held "probe" will result in severely limited accuracy. Indications obtained in this way should be understood to be only approximate and are limited to low frequencies.

Fixtures

Fixtures may be used for either: (1) mounting transducers to a test specimen, or (2) mounting a specimen to some source of input energy, such as a vibration "shaker". In either case the fixture, to be successful, must transmit the motion throughout the test frequency range without distortion. In vibration testing, fixtures originally designed for testing at low frequencies should not be used for programs involving high frequencies. Many fixtures have resonance points that are below 2 kHz with Q's of 10 or more. This may result in severe under- or over-testing with resultant high component failure rates or over-design.

In order to properly design a fixture, the exact nature of its use must be known — frequency range, g level and, of course, the mechanical specifications of the test object. Individual fixtures should be designed for each component or instrument to be tested above 500 Hz. A fixture that introduces spurious response into the test is not satisfactory. However, since it is impossible to design the ideal fixture, it is mandatory that its exact characteristics be known before it is put to use. Not only must the fixture be carefully designed, but it must be tested and the vibration plotted at several points on the fixture. The more complex the structure, the more points to plot.

Effects of Mounting

In some instances, the very act of performing a measurement affects the system being measured and, thus, changes the nature of the data obtained. With piezoelectric accelerometers, this may occur for two reasons: (1) the fixture required to couple the accelerometer to a somewhat flexible structure may introduce local stiffening which changes structural response, and (2) the added mass of the fixture and/or transducer may change the system characteristics. Effects due to either cause can be reduced or eliminated by choosing as small and light an accelerometer as possible. Endevco® Miniature Accelerometers (Models 22 and 23) weigh less than a gram and are small enough to approach point loading in many cases.

For a simple spring-mass structure, the effect of adding an accelerometer is to reduce the system's resonance frequency. The amount of reduction can be calculated from the following equation:

$$\Delta f_n = f_n \left(1 - \sqrt{\frac{m}{m_a + m}} \right) \qquad (8)$$

Where:

f_n = resonance frequency of the structure

Δf_n = change in resonance frequency

m = mass of the structure

m_a = added mass of the accelerometer

A more general approach to loading effects is based on mechanical impedance* considerations. Since piezoelectric accelerometers have nearly zero internal damping, the apparent weight (and mechanical impedance) of the accelerometer is constant at all frequencies from zero up to approximately 0.9 of its resonance frequency and must be equal in value to its physical weight. Within this range, the effect of the accelerometer on the structure motion is given by:

$$a_r = a_o \left(\frac{m_s}{m_s + w_t} \right) \qquad (9)$$

Where:

a_r = resultant acceleration

a_o = acceleration without accelerometer attached

w_t = weight of accelerometer

m_s = apparent weight of structure

This statement of *Norton's Theorem* indicates that mounting an accelerometer will change the motion of a structure if the structure's apparent weight is not large compared to the total weight of the accelerometer. For most applications, the effect of the accelerometer on structure motion is not significant and the apparent weight of the accelerometer may be ignored.

*Mechanical impedance (Z) of a structure is defined as the force (F) applied to (a point on) the structure divided by the velocity (V) which results from the applied force. The defining equation is: $Z = \frac{F}{V}$. All terms are vectors and the phase angle between the applied force and resultant velocity must also be known to completely define the impedance of that point in structure.

In actual measurement of mechanical impedance, it is frequently more convenient to measure resultant acceleration, rather than velocity. When force and acceleration are known, the equation F = ma applies, from which is derived the defining equation: $m = \frac{F}{a}$. When acceleration is measured in units of g's, m represents apparent weight. If acceleration is measured in terms of basic units (cm/sec^2, in/sec^2, etc.) m is apparent mass.

3.2 Cables

The cable which connects a transducer to its matching electronics is an important part of the over-all measurement system. It must transmit the transducer signal to the associated signal conditioning equipment without distortion or introduction of noise.

Noise can be introduced either by pickup from nearby electrical (or magnetic) fields or by internal generation due to cable motion. Since piezoelectric accelerometers are high impedance devices, the pickup problem could be quite severe. For this reason, coaxial or shielded twisted-pair cables are required.

When coaxial cable is flexed, squeezed, or in some other way mechanically distorted, the shield and dielectric may separate, resulting in the generation of some triboelectric charges (see Figure 9). The charges on the dielectric are trapped by the low conductivity of the dielectric material. The charges on the shield, however, are mobile and neutralize by flowing from the inner conductor through the terminating impedance, generally the input stage of the coupling amplifier. This momentary current flow produces a signal pulse at the amplifier input. When the cable distortion is relieved, dielectric and shield are joined together and the formerly trapped electrons now flow into the shield, resulting in a second pulse of opposite polarity. (Untreated cables can generate noise of greater amplitude than the output of the accelerometer!)

Noise treated cables have a conductive coating applied to the surface of the dielectric which prevents buildup of local charges during mechanical separation from the shield. This treatment, therefore, greatly reduces triboelectric noise. This type of cable should be used whenever a cable is subjected to bending stresses.

In addition to good noise characteristics, the cable must not affect transducer or test specimen characteristics. Good transducer cables are as small, light, and flexible as possible, considering their specific intended application. Stiff or massive cables can severely distort normal response, particularly with light, flexible specimens.

Each Endevco® accelerometer is provided with a low noise subminiature coaxial cable assembly. In

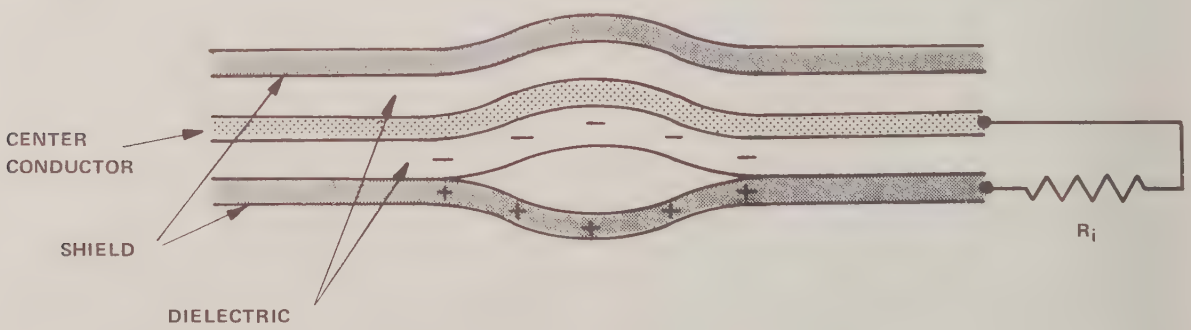


Figure 9. Triboelectric effect in coaxial cables.

addition to testing for conformance to specification, the exact capacitance of each cable assembly is measured and shown on an attached tag.

Length of each cable assembly is indicated by a dash number following the cable model number which gives length in inches. For example: 3090A-36 is a 3090A Cable Assembly (see below) 36 inches in length. Connectors are provided on each end.

3030 Cable should be used only as an extension cable. Outer jacket is orange polyvinyl chloride and dielectric material is polyethylene. Nominal capacitance is 30 pF per foot and rated temperature range −65°F to +175°F (−54°C to +80°C).

3060A Cable is high temperature cable with excellent flexibility. Outer jacket is red silicone rubber and the dielectric material is Teflon®. Nominal capacitance is 40 pF per foot and rated temperature range is from −100° to +500°F (−73°C to +260°C).

3070 Cable is a special, very high temperature and radiation resistant cable, rated to +750°F (400°C). It has no outer jacket and the braided stainless steel shield is exposed. Dielectric material is a special refractory fiber. Nominal capacitance is 30 pF per foot. Low temperature use is limited to low humidity environment.

3075 Cable has a solid stainless steel jacket, 0.070 inches diameter. Temperature range is −300°F to +900°F, (−184°C to +482°C).

3090A Cable is recommended for general high temperature use. Outer jacket is red Teflon® as is the dielectric. Nominal capacitance is 30 pF per foot, and temperature range is from −450°F to +500°F, (−270°C to +260°C).

3090B Cable is a low noise, Teflon® jacketed cable designed for severe environments. Nominal capacitance is 30 pF per foot, and temperature range is −452°F to 500°F (−270°C to 260°C). The connectors have fused glass insulator and center pin is welded to the cable center conductor.

3091D and 3093 Cable are special, very small diameter cable for use with the Model 2220C and other Microminiature Accelerometers. Outer jacket is red Teflon® as is the dielectric. Nominal capacitance is 30 pF per foot. Temperature range is from −300°F to +350°F (−184°C to +177°C) for 3091D and −100°F to +350°F (−73°C to +177°C) for 3093.

For more detailed specifications on these and other Endevco® transducer cables, ask for Model 3000 Series Data Sheet.

Although fairly rugged, these cables should be handled with care – they can be damaged if misused. They should *not* be stepped on, kinked, knotted, etc. When attaching (and detaching) cables, care must be taken not to bend the center pin of the cable connector, which is relatively susceptible during these operations. Cable connectors should be securely tightened.

When possible, the cable should be tied down within 2 to 3 inches of the transducer connection. Long unsupported length of cable may load the test specimen and lead to cable damage. Good housekeeping should be observed – excess cable should be neatly coiled and tied down. In humid environments, it is good practice to provide a drip loop at the accelerometer. It may also be advisable to seal the cable connector to prevent moisture from entering the cable assembly. If the connector insulation has become damp (or otherwise contaminated), it should be wiped dry with alcohol or a dry, clean cloth.

At very high sustained vibration levels, the energy present is sufficiently high that considerable heat is generated in the accelerometer cable. (Several minutes at 3000 g and 6 kHz heats the cable bend relief enough that the accelerometer is too hot to touch.) For this reason, high temperature cable such as Model 3090A should be used in applications where high frequency continuous sinusoidal vibration exceeding 100 g will be encountered. In severe cases, heating can be reduced by removing the cable bend relief entirely and stripping off a few inches of the outer (Teflon®) jacket.

3.3 Electronics

Piezoelectric accelerometers can be operated into either charge sensing or voltage sensing electronics. Both types of equipment are available in a wide variety of configurations designed for either (1) laboratory, (2) test stand, or (3) airborne applications.

Charge amplifiers sense the actual charge developed in the crystal. System sensitivity is unaffected by the length of cable between accelerometer and amplifier or by changes in cable length. This means that an accelerometer–charge amplifier system can be calibrated in the laboratory with any convenient length of cable and the calibration will still be valid when installed in, say, an aircraft in which the cable is already installed in a prewired harness.

A piezoelectric transducer voltage amplifier has, typically, an input resistance of 1000 megohms and requires the source resistance to be significantly greater than that for adequate low frequency response. Charge amplifiers will operate satisfactorily with as low as 10 megohms input shunt resistance. In a charge amplifier system, the low frequency response is not a function of input RC time constant, but is determined only by the amplifier frequency response characteristics.

A voltage amplifier may provide gain or may be simply a cathode follower, with unity gain. The high input impedance provides a matched termination for the high internal source impedance of the accelerometer. With higher input resistance, the RC time constant increases for improved low frequency response. System sensitivity will be reduced as longer interconnecting cables are used between accelerometer and amplifier.

3.4 Systems

In addition to the characteristics of each component of the measurement system, the operation of the system as a whole must be considered. One particularly important system consideration is prevention of ground loops. The problem can occur when the common connection (or signal return) in the system is grounded at more than one point (Fig. 10). Differences in earth potential up to several volts may exist between various grounding points. This potential difference can produce circulating ground currents that introduce noise in the measuring system.

The only method of preventing ground loops is to ensure that the entire system is grounded at a single point. In general, the most satisfactory system ground point is at the readout input. (When several channels of data are being simultaneously fed to the same recorder, it is mandatory.) This requires that both accelerometer and amplifier be insulated from ground.

One technique of accelerometer isolation involves electrically insulating the sensing element from the transducer housing to provide a floating output. With this approach the accelerometer case is at ground potential, but is not connected to the "low side" of the signal. This method, however, has a serious drawback. Capacitive coupling between case and transducer element permits coupling of AC noise directly into the (high impedance) transducer.

A much better and simpler technique is to electrically isolate a normal accelerometer from the structure to which it is mounted. Using this method, while the accelerometer is removed from earth ground, the transducer element is still shielded by the transducer case which is at circuit ground potential. This grounded shield is required to prevent capacitive coupling problems. Insulated mounting can most conveniently be achieved using one of the series of Endevco® insulated mounting studs. They provide good transmissibility and insulation resistance over a wide range of frequencies and acceleration levels. (See Model 2980 Series Accelerometer Mounting Stud Data Sheet).

When using cementing techniques, isolation can be ensured by "sandwiching" a rigid insulating material (such as Mycalex) between the structure and accelerometer (or base of cementing stud). Dental cements alone are also quite satisfactory insulators.

Matching electronics in which the case is tied to circuit ground can be satisfactorily isolated by wrapping with insulating material (electrical tape, etc.) or by simply placing on paper or cardboard. (In severe environments, the amplifier can be wrapped with sponge rubber.)

If amplifier output cables are unjacketed, care must be taken that any exposed shields or connectors do not become inadvertently grounded ahead of the recorder input.

System Calibration

The best method of determining accelerometer system performance is by true dynamic calibration of the entire operating system. In the laboratory, such calibration can be readily performed with good accuracy using electrodynamic shakers. In field testing, however, shaker calibration is usually impractical. Instead, a voltage substitution technique is frequently employed. This procedure, also called

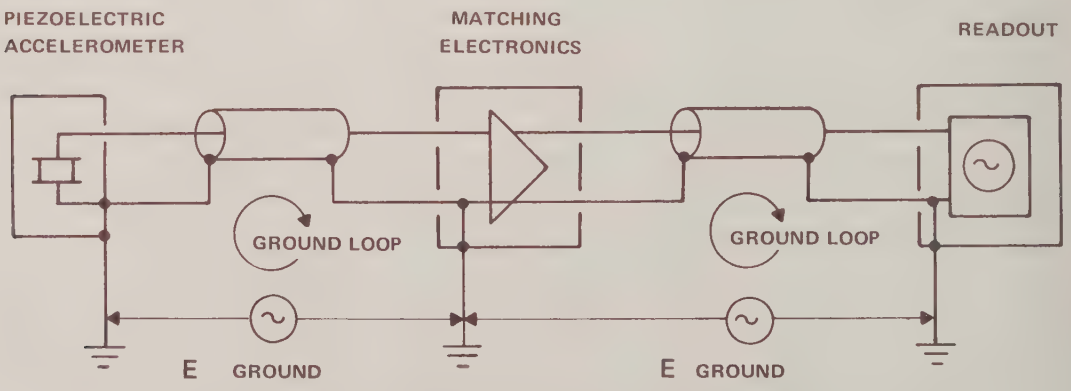


Figure 10. Ground loops in typical piezoelectric accelerometer installation (after Conrad).

"calibration simulation", does *not* calibrate the entire system. Instead, a simulated transducer output is provided which (1) checks system continuity, (2) permits proper setting of system gains, (3) evaluates electrical performance of preamplifiers, signal conditioning equipment, readout and data storage devices under conditions which closely simulate the actual measurement situation.

The usual method is to insert a voltage signal in series with the ground side of the transducer cable (Fig. 11). This may be accomplished by breaking the ground side and inserting a calibration resistor, across which a predetermined calibrating signal is applied.

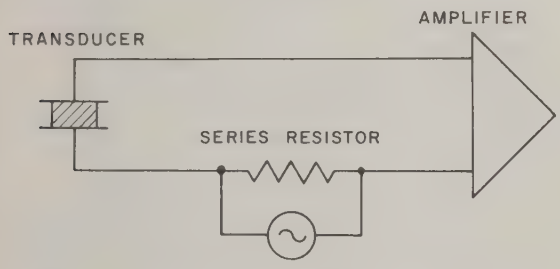


Figure 11. Calibration simulation method used with piezoelectric accelerometer systems.

The signal is coupled through the transducer, acting here only as a passive coupling capacitor and into the system. Physically, the resistor may be either inside the amplifier case, inside the accelerometer, or inserted (electrically) into the cable by means of a "tee" junction (Model 2944.1). For detailed information regarding the use of this technique, see Endevco Technical Paper No. 216, "Piezoelectric Transducer Calibration Simulation Method Using Series Voltage Insertion", J. Rhodes.

3.5 Shock Testing

In addition to the foregoing information, which is valid for both vibration and shock work, special problems are encountered in shock testing which place stringent requirements on the measuring system.

Some of these problems are:

1. High g levels
2. Wide frequency content of pulses
3. Transient characteristics of instrumentation

As a result, each part of the shock instrumentation systems should be evaluated and selected for:

1. Adequate linear dynamic range (including safety factor)
2. Adequate linear frequency response over a wide range
3. Ability to respond to transient inputs
4. Negligible phase shift errors over the frequency range of interest

Dynamic Range

The accelerometer should be selected for its ability to meet the linear dynamic range required. All Endevco accelerometers are rated for both linear dynamic range for maximum dynamic input without damage ("Environmental" rating). For high shock levels (above 1000 g) the preferred choices are: Model 2292 (to 20,000 g), and Model 2291 (to 100,000 g) shock accelerometers.

Care should be taken that the signal output does not overload the associated electronics. With voltage amplifiers capacitive swamping may be utilized to reduce the signal level. The Model 2740 Charge Amplifier, on the other hand, will operate with either of the recommended accelerometers and provide undistorted full scale output for 100,000 g (or more) without need for any signal attenuation. A peak holding display, which permits the maximum value of the shock pulse to read directly, may be connected to the 2740 as an accessory.

For an accelerometer of known sensitivity and a given shock input, the signal which the amplifier must handle can be computed.

The gain of the related amplifier must be constant over the entire dynamic range of the input signal and be adequate to provide full scale output for the expected input.

Low Frequency Response

Inadequate low frequency response in the measurement system will result in failure to accurately reproduce the shock pulse. The nature of this inaccuracy can be seen by examining the effect on a rectangular pulse of duration T and amplitude A.

If this transient is passed through a system with first order low frequency response*, the resultant output

*A first order system has the same low frequency response as a single resistor-capacitor high pass filter whose time constant in seconds is equal to RC (ohms x farads). Such a system exhibits a low frequency rolloff at 6 dB/octave. It is 3 dB down at a frequency equal to $\frac{1}{2\pi RC}$ and 5% down at a frequency of $\frac{3}{2\pi RC}$

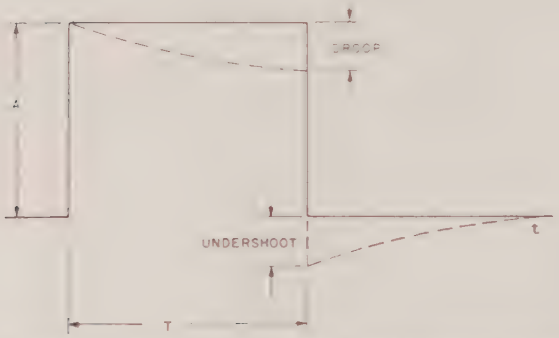


Figure 12. Response of a system with first order low frequency response to a rectangular pulse. (Input pulse is solid line, dashed line shows system response.)

will be as shown in Figure 12. The output does not remain at the peak value for the full pulse duration, but decays exponentially. The output amplitude at any instant (during the pulse) can be expressed as:

$$a = Ae^{-t/RC}$$

where RC is the system time constant.

At the termination of the pulse, the output does not return to zero but overshoots in a negative direction. Recovery from this "undershoot" occurs at the same exponential rate as droop.

The ratio of droop to total height is considered the error and is a function of the ratio $\frac{T}{RC}$ The smaller the ratio, the less error (and the less undershoot).

For example, if the ratio $\frac{RC}{T}$ is 20, there will be approximately 5% error in the rectangular pulse amplitude; if the ratio is 50, there will be only 2% error.

Although slightly more complex to analyze, it can be shown that similar low frequency effects occur for other pulse shapes. Figure 13 shows the effect of $\frac{RC}{T}$ for the three most common shock pulses. For the half-sine and sawtooth pulses, a ratio of 7 is required for 5% error, and a ratio of 16 for 2% error.

Note that if the requirement for adequate $\frac{RC}{T}$ is not satisfied, it is possible to predict the degree of error for these pulses and apply appropriate correction factors to the data obtained.

For example, for a half-sine pulse, Table 2 lists the correction factors involved when the indicated peak fails to reach the actual peak and a spurious undershoot is noted at the termination of the pulse.

Table 2.
Undershoot on Half-Sine Pulses

Indicated Undershoot % / Indicated Peak	Actual Peak / Indicated Peak	Approximate $\frac{RC}{T}$
5%	1.04	9.0
10%	1.06	6.0
15%	1.08	4.0
20%	1.11	3.0
25%	1.15	2.1
30%	1.19	1.7
35%	1.21	1.5
40%	1.25	1.3
45%	1.28	1.2
50%	1.32	1.0
100%	1.90	0.4

For half-sine pulses, a useful rule of thumb for small undershoots is to consider that the required correction to the peak value is approximately half the undershoot.

For rectangular and sawtooth pulses, the rule of thumb for small undershoots is to consider the required correction to the peak value is approximately equal to the undershoot.

Ideally, the measurement system should have response down to DC (0 Hz). In practice, response approaching DC is sufficient to keep low frequency error within a few per cent. This is usually well within the other cumulative errors in the over-all measuring system.

When using a voltage amplifier, the transducer low frequency response is determined by the RC product of (a) the amplifier or cathode follower input resistance, and (b) the total transducer system capacitance. The latter consists of the transducer capacitance, cable capacitance, input capacitance of the cathode follower or amplifier – all added in parallel along with any capacitance introduced intentionally.

A useful relationship between RC time, input resistance and capacitance is as follows:

$$t = 1000\ RC$$

$$RC = \frac{t}{1000}$$

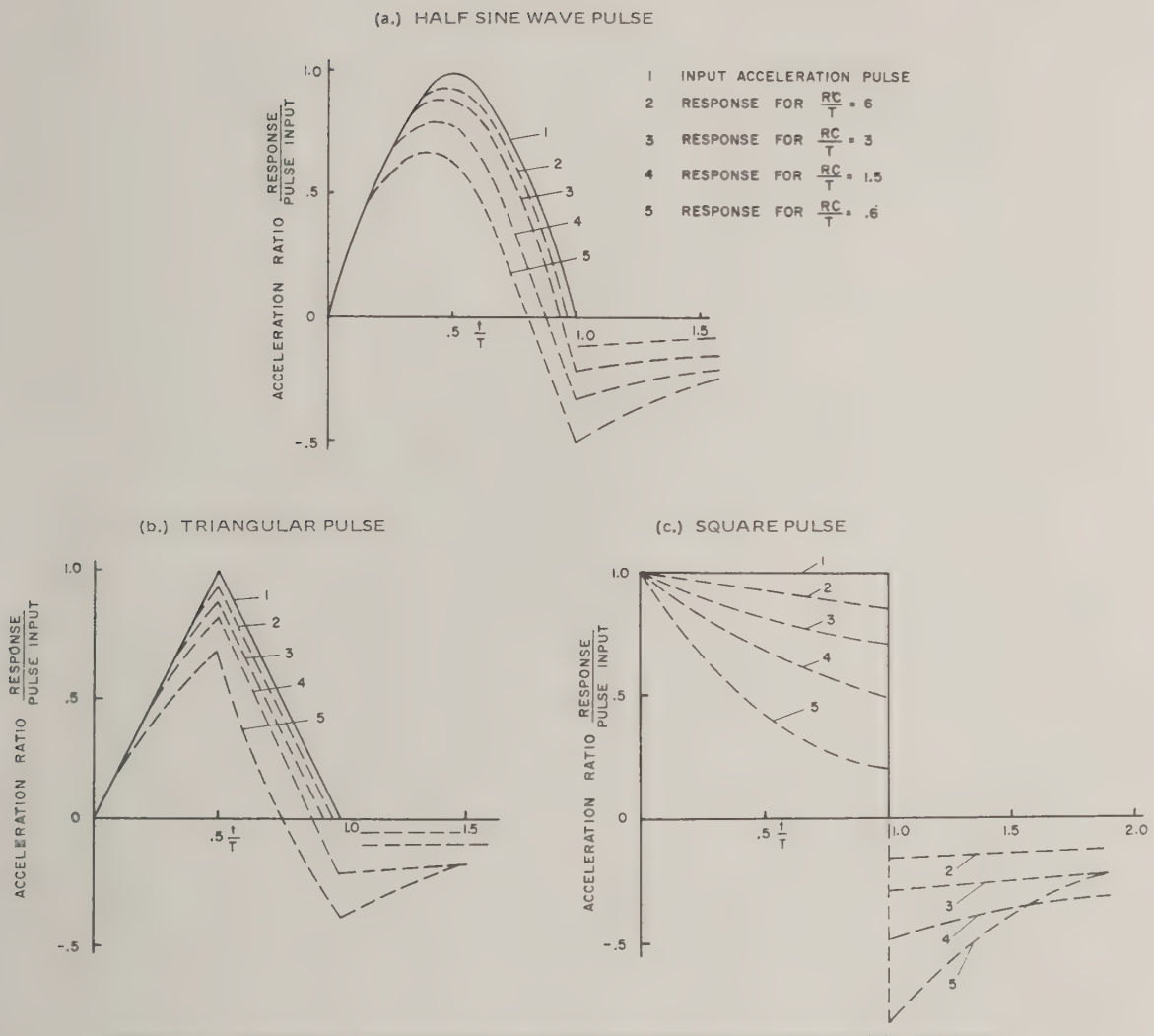


Figure 13. Response of a system with first order low frequency response to (a) a half-sine, (b) a triangular, and (c) a rectangular pulse for various values of RC/T.

Where:

t is the RC time constant in msec
R is the input resistance in MΩ
C is the system capacitance in pF

With charge amplifiers, the transducer low frequency response is determined solely by the charge amplifier low frequency characteristic.

Low Frequency Requirements

The low frequency requirement for either 2% or 5% accuracy for varying durations of half-sine, sawtooth and rectangular pulses are shown graphically in Figure 14.

When using voltage systems, use the right hand ordinate labeled "RC Time Constant" — for charge systems use the left hand ordinate labeled "Low Frequency Limit (5% down)."

Example: With a voltage amplifier, to measure an 11 millisecond sawtooth pulse with 2% accuracy, the RC time must be, from Figure 14, 0.18 seconds. If the voltage amplifier input resistance is 100 megohms, the required system capacitance is 0.18 divided by 10^8 = 1800 pF.

Suppose transducer capacitance is 700 pF, cable capacitance is 300 pF and amplifier input capacitance is 25 pF. Then additional shunt capacitance equal to 1800 pF minus (700 + 300 + 25) pF = 755 pF must be added to attain 2% accuracy.

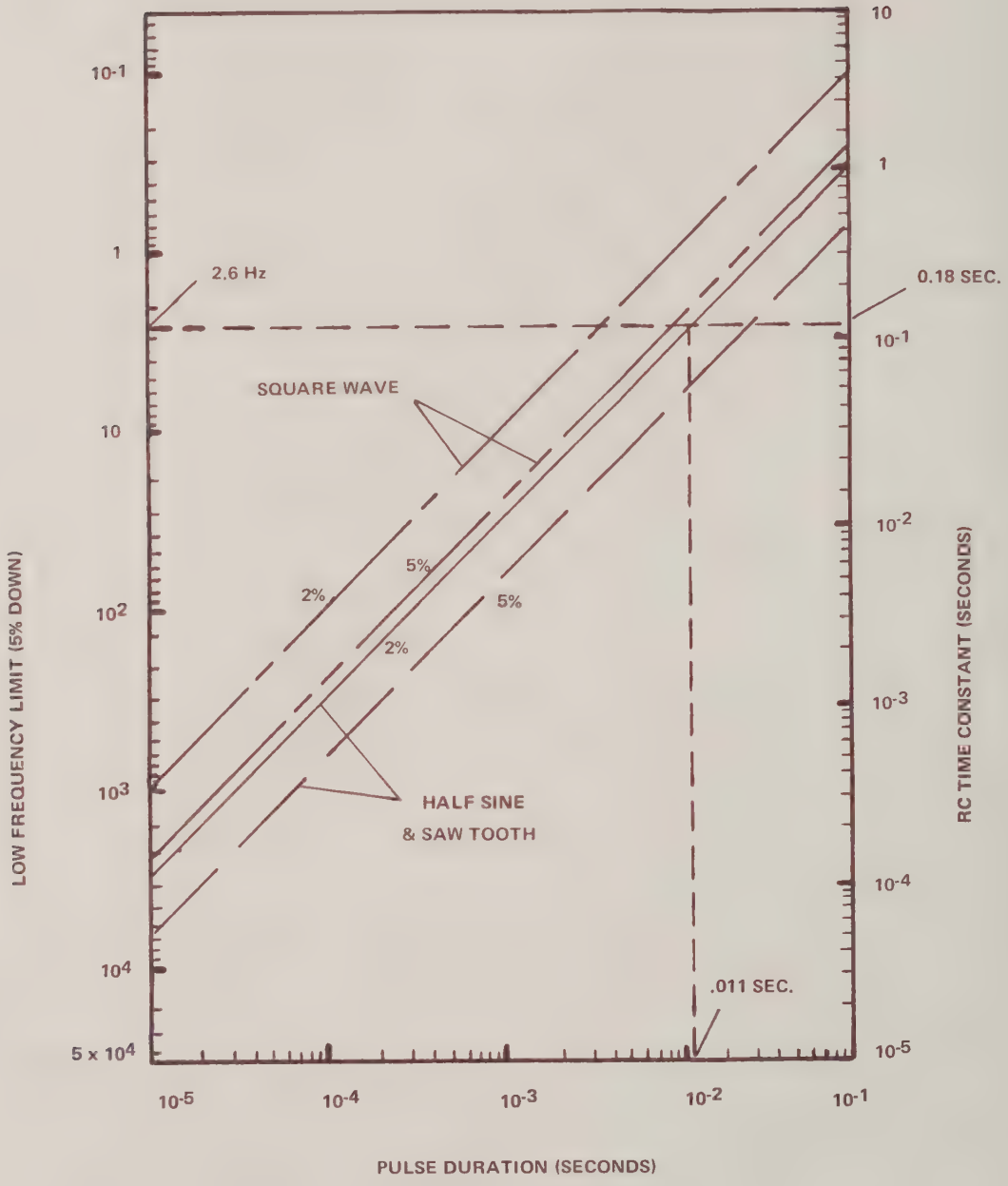


Figure 14. System low frequency response requirements for accurate measurement of acceleration pulses.

The same measurement performed with a charge amplifier requires, from Figure 14, a 5% down low frequency response of 2.6 Hz.

The readout device is usually an oscilloscope with a DC amplifier, a galvanometer with a driving amplifier that has adequate low frequency response, or a peak reading meter. The readout device and any intermediate cathode followers, amplifiers or filters must also meet the low frequency response requirements outlined above.

High Frequency Response

Consider again a rectangular pulse of duration T and amplitude A. If this transient is passed through a system with first order high frequency response (corresponding to a single RC low pass filter combination) the resultant output will be shown in Figure 15. The effect of the high frequency rolloff is to slow the rise time of the pulse, thus rounding both the leading and trailing edges.

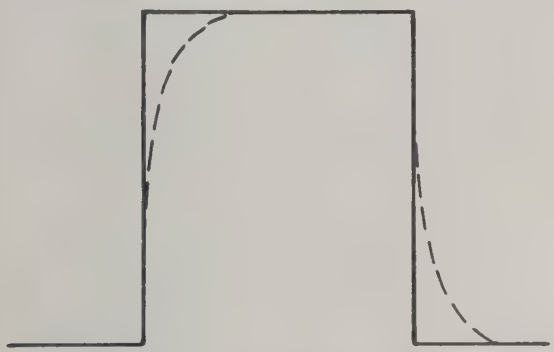


Figure 15. Response of a system with first order high frequency response to a rectangular pulse.

It is also of interest to note the effect of passing the rectangular pulse through a system possessing second order high frequency response. (Such a system corresponds to the electrical frequency response of a single LC low pass filter combination.) Figure 16 shows the resulting output. A high frequency ringing at approximately the high frequency cutoff frequency is superimposed on the shock pulse. The amplitude and duration of the ringing depend on the damping factor,

Fourier analysis show that short transients contain significant high frequency components. Both the transducer and associated equipment must have adequate high frequency response to avoid undesirable measurement distortion.

The high frequency response of a piezoelectric accelerometer is approximately a second order function with very little damping and is determined by the transducer resonance frequency.

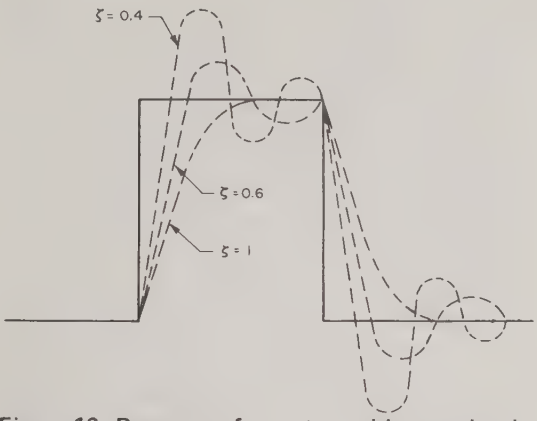


Figure 16. Response of a system with second order high frequency response to a rectangular pulse for various values of the damping factor.

The use of such devices provides desirable high frequency response along with minimum phase shift in the frequency range of interest.

Transients, however, may excite such a transducer to resonance; natural frequency "ringing" will then be superimposed on the basic transient.

In the case of short, rectangular or other transients with essentially zero rise time (very short rise time in proportion to the natural period of the transducer) almost 100% overshoot on the transient may occur along with subsequent excitation of accelerometer natural frequency. To minimize or prevent these distortions, the accelerometer should have a natural period one third the expected rise time or less.

With half-sine or sawtooth transients, the transducer natural period (the reciprocal of natural frequency) should be less than one fifth the pulse duration. This ensures that the indicated peak does not exceed 10% of the actual peak. Ten per cent has been arbitrarily chosen as a desirable limit for practical work.

Resonance frequencies should be as shown in Table 3 in order that the natural period be one fifth the pulse duration.

Table 3.
Required Resonance Frequency
For
Undamped Transducers Measuring Half-Sine
or Sawtooth Transients

Pulse Width	Required Natural Period	Required Resonance Frequency
200 μ sec	40 μ sec	25 kHz
150 μ sec	30 μ sec	33 kHz
100 μ sec	20 μ sec	50 kHz
75 μ sec	15 μ sec	67 kHz
50 μ sec	10 μ sec	100 kHz

It might be inferred from Table 3 that the transducer resonance frequency can be less that 25 kHz for pulses longer than 200 μsec. This would be true if the pulse were *strictly* half-sine or sawtooth; however, in practice many pulses contain "high frequency hash" as a result of mechanical resonances from testing equipment or the structure under test. These may excite a low transducer resonance; it is, therefore, advisable to have a transducer resonance of at least 25 kHz even for long pulses.

In addition to a high resonance frequency, the transducer frequency response and phase shift characteristics should ideally follow the characteristic response for an undamped single-degree-of-freedom mechanical system to minimize distortion. Endevco® accelerometers do so.

If the matching amplifier possesses high frequency response flat to at least one-half the accelerometer resonance frequency, no appreciable error will be introduced by amplifier rolloff characteristics.

Readout Devices

The most common types of readout devices are: (1) Oscilloscope, (2) Galvanometer, and (3) Magnetic Tape. Another, less common device is the single peak reading meter, used where only the peak value of the shock is of interest. The oscilloscope is probably the most versatile and easy to use. A good quality scope will have response (from DC) to above a megacycle so that it will not introduce any errors.

Galvanometer recorders are damped readout devices that serve to filter frequency components higher than the galvanometer resonance frequency. The galvanometer resonance frequency should be high so that minimum distortion of the basic transient is introduced. For a galvanometer damped to approximately 70% of critical damping, a resonance frequency of at least 400 Hz is desirable for recording 10 msec half-sine transients. For shorter half-sine transients, the resonance frequency should be higher in inverse proportion to the transient duration. Conversely, the galvanometer resonance frequency can be correspondingly lower for longer half-sine transients.

Magnetic tape recording is most useful where the shock information is to be fed into a computer for data reduction. In general, the shock information is processed before recording to put it in the form which the magnetic tape and computer can accept. When this is done, the high frequency response is limited in some cases.

If the shock measuring system is to be airborne such as in a missile instrumentation, the telemetering link must be considered. Normally, this would include a voltage controlled oscillator and a telemetering transmitter. The center frequency of the VCO must be chosen sufficiently high so that distortion of the shock pulse does not occur due to the high frequency rolloff of the telemetering system.

Phase Shift and Filtering

Faithful reproduction of transients requires that the shock measurement system be free from phase distortion. As we have seen, undamped Endevco® accelerometers exhibit 0° phase shift over their useful frequency range and thus are not a source of this type of error. Matching amplifiers should be chosen for acceptable phase characteristics. Recording galvanometers, when properly damped, exhibit linear phase shift over their usable frequency range. Other readout devices do not, in general introduce phase distortion. The greatest potential source of phase error with piezoelectric accelerometer systems is low pass filters sometimes employed to eliminate high frequency ringing superimposed on the basic transient.

If a virtually undamped accelerometer is subjected to a shock that causes it to resonate, the magnitude of the accelerometer output does bear a fixed relationship to the mechanical input. This relationship, however, is so sharply dependent upon the input shock duration and rise time that the output signal is rarely of practical value.

It is usually possible to select an accelerometer with a high enough natural frequency that it will not resonate for a given shock input. For example, the Model 2292 Accelerometer exhibits a mounted resonance frequency of approximately 125 kHz.

In some cases, when rise times are extremely short, it may become necessary to resort to electrical filtering. The data in the pass band of a low pass filter will have quantitative value, even if the transducer is resonating, as long as the filter has a linear phase shift characteristic (constant delay). If high frequency quantitative data is desired, allowances must be made for the rolloff characteristic of the filter.

When filtering is used in the measuring system, the actual and recorded transients may differ widely. For this reason, it is strongly recommended that the unfiltered response from the transducer be recorded as well.

Zero Shift

Accelerometer zero shift is defined as the failure of the output of a piezoelectric accelerometer to return to the same zero line after the applied acceleration has ceased. It appears as a dc offset which generally returns to the original zero at an exponential decay rate. This rate is usually determined by the effective RC time constant of the accelerometer-amplifier system.

The basic cause of zero shift is overstress in the accelerometer crystal element. Under certain conditions, the output of an accelerometer-amplifier system may exhibit a wave shape similar to that of a zero shift, due to input cable and electronic effects.

Accelerometer overstress can be avoided by selecting an accelerometer with a dynamic range much higher than that expected in testing. The apparent zero shift caused by cable motion and electronics can be prevented by careful choice of cable routing and amplifiers.

A current hypothesis, based upon considerable testing and research, is that zero shift in ceramic piezoelectric accelerometers is caused by a very slight depolarization of the crystal element. This depolarization apparently occurs as a result of the high local stress produced when an accelerometer is overranged. In type P-8 crystal designs, a depolarization of 0.001% produces approximately 400 pC of charge, a measurable zero shift in some test applications. This small depolarization has no measurable effect on the sensitivity of the accelerometer after the shock measurement is completed. The increase in sensitivity, present during the shock motion, is usually known and is discussed in Section 2.6, Dynamic Range and Linearity.

Because piezoelectric accelerometers have a high amplification factor at resonance, resonance ringing due to very short input pulses or structure resonance may cause higher crystal stress than expected, resulting in zero shift. Repeated shocks sometimes reduce zero shift. Unfortunately, this reduction is not monotonic or permanent. As would follow from the depolarization theory, zero shift caused by crystal overstress has the same polarity as the unidirectional pulse which initiates it. In situations where resonance ringing is prominent, the polarity of the shift may be positive or negative.

Tests conducted at Endevco have shown that accelerometers using polycrystaline or single crystal piezoelectric materials can exhibit zero shift if subjected to high enough acceleration levels. In this phenomenon the crystal material is an important factor, but even more so is the accelerometer design. The Model 2292 Accelerometer shows less than 1% zero shift to 20,000 g; and the Model 2291 exhibits considerable less than 1% zero shift to 60,000 g. In all shock applications where absence of zero shift is important, either the 2292 or 2291 accelerometer should be used.

Poorly supported cable can place a high stress on the accelerometer connector. In an accelerometer with a high base strain sensitivity, this stress may produce a spurious output which may appear as a zero shift. Also, a cable slapping against a fixture or test specimen can generate a spurious signal that appears as distortion or zero shift.

In an accelerometer-amplifier system, an apparent zero shift in the output may be due to inadequate low frequency response of the amplifier for the applied pulse duration. This dc offset is known as "undershoot", and it is always opposite in polarity to the applied pulse. See Section 3.5, Shock Testing, Low Frequency Response. Sufficiently high input signals may cause an amplifier to block or remain inoperative for a short period of time. In this case, the output appears as a dc offset, which returns to zero with an exponential decay.

Other Spurious Outputs

The extremely high accelerations encountered in shock applications can result in other spurious outputs. One source of noise which can become troublesome is signal generation by the transducer cable. Even the specially noise-treated cables supplied by Endevco may produce noise when subjected to very high shock.

This problem can be minimized by:

(a) Using only fresh, undamaged cable
(b) Attaching cables securely to prevent slapping or other motion
(c) Using higher output accelerometers to improve signal-to-noise ratio.

Spurious signals may also be introduced by shock excited filters which ring at their characteristic (cutoff) frequencies. This problem can be eliminated by proper damping of the resonating elements.

3.6 Check List

3.6.1 Instrument Selection

Transducer

Will the accelerometer operate satisfactorily in the measurement environment?

Check:

Temperature Range
Maximum Shock and Vibration
Humidity
Pressure
Acoustic Level
Corrosive Gases
Magnetic and RF Fields
Nuclear Radiation
Salt Spray
Transient Temperatures
Bending of Mounting Surface

Will the accelerometer characteristics provide the desired data accuracy?

Check:
- Sensitivity
- Frequency Response
  - Resonance Frequency
  - Internal Capacitance
- Transverse Sensitivity
- Amplitude Linearity
- Temperature Deviation
- Weight
- Internal Resistance at Maximum Temperature
- Calibration Accuracy
- Strain Sensitivity

Is the unit in good condition and ready to use?

Check:
- Up-to-Date Calibration
- Physical Condition
  - Case
  - Mounting Surface
  - Connector
  - Mounting Threads
- Inspect for Clean Connector
- Internal Resistance

Is the proper stud being used for this application?

Check:
- Is Insulating Stud Required?
  - Ground Loops
  - Calibration Simulation
- Is Cementing Stud Required?
  - Thread Size

Is the stud in good condition and ready to use?

Check:
- Mounting Surface Condition
- Thread Condition
- Burred End Slots
- Insulated Stud
  - Insulation Resistance
  - Stud Damage by Over Torquing

Cable

Will the cable operate satisfactorily in the measurement of environment?

Check:
- Temperature Range

Will the cable characteristics provide the desired data accuracy?

Check:
- Low Noise
- Size and Weight
- Flexibility
- Is Sealed Connection Required?

Is the cable in good condition and ready for use?

Check:
- Physical Condition
  - Cable Kinked, Crushed
  - Connector Threads, Center Pin
- Inspect for Clean Connectors
- Continuity
- Insulation Resistance
- Capacitance

Amplifier

Will the amplifier operate satisfactorily in the measurement environment?

Check:
- Temperature Range
- Maximum Shock and Vibration
- Humidity
- Pressure
- Acoustic Level
- Corrosive Gases
- Magnetic and RF Fields
- Nuclear Radiation
- Salt Spray

Is this the proper amplifier for the application?

Check:
- Long Input Lines?
  - Need for Charge Amplifier
  - Need for Remote Charge Amplifier
- Long Output Lines?
  - Need for Power Amplifier
- Airborne?
  - Need for Solid-State Potted Amplifier

Will the amplifier characteristics provide the desired data accuracy?

Check:
- Gain
- Frequency Response
- Linearity
- Stability
- Phase Shift
- Output Current and Voltage
- Residual Noise
- Input Impedance
- Transient Response
- Overload Capability

Is the unit in good condition and ready to use?

Check:
- Up-to-Date Calibration
- Physical Condition
  - Connectors
  - Case
  - Output Cables
- Inspect for Clean Connectors

Readout

Does the remainder of the system, including any additional amplifiers, filters, and readout devices introduce any limitation that will tend to degrade the transducer-amplifier characteristics?

Check: *All* of previous check items, plus adequate resolution

3.6.2 Installation

Transducer

Stud Mounting:
- Mounting Surface Clean and Flat
- Transducer Base Surface Clean and Flat
- Hole Drilled and Tapped Deep Enough
- Correct Tap Size
- Hole Properly Aligned Perpendicular to Mounting Surface
- Stud Threads Lubricated
- Accelerometer Mounted with Recommended Torque
- Light Oil for High Frequency Measurements above 5 kHz

Cement Mounting:
- Mounting Surface Clean and Flat (Dental Cement for Uneven Surfaces)
- Cement Cured Properly
- Accelerometer Mounted to Cementing Stud with Recommended Torque

Cable

Check:
- Cable Connected Securely to Accelerometer
- Cable Tied Down 2 to 3" from Connector
- Excess Cable Coiled and Tied Down
- Drip Loop Provided
- Connectors Sealed and Potted, if Required
- Cable Connected Securely to Amplifier

Amplifier

Check:
- Mounted Securely
- All Cable Connections Secure
- Gain Hole Cover Sealed, if Required
- Recommended Grounding in Use

4.0 MAINTENANCE AND WARRANTY

4.1 Accelerometer Maintenance

CAUTION: Care must be taken while handling piezoelectric accelerometers. Typical Endevco® transducers, dropped from a height of 3 feet to a typical laboratory floor, wood or asphalt tile, are subjected to a shock amplitude of 3000 to 5000 g. This shock will damage transducers rated for a lower environmental shock limit. Furthermore, nicks, scratches, or other deformation of the mounting surface will increase transverse sensitivity and degrade frequency response. Inspect the accelerometer before using it.

Endevco® accelerometers are designed to give many years of service without maintenance when used within specification limits. Accelerometers that behave erratically should be checked for loose cable connections. Accelerometers exhibiting poor low frequency response are usually corrected by inspecting cables and connections with a megohmmeter to determine if a low resistance leakage path exists somewhere in the system. The insulation resistance of a properly operating system should be well above 10,000 megohms. It should be noted that wiping damp or oily fingers across the coaxial connectors will provide a leakage path well below this figure, resulting in poor low frequency response. Insulation resistance can be restored by wiping all connectors with a dry cloth.

4.2 Recalibration

Recalibrations of sensitivity and frequency response should be performed at 6- to 12-month intervals, depending on usage. Ordinarily, recalibrations need be performed only at 12-month intervals if it is known that the accelerometer has not been used beyond its rated specifications. If the accelerometer is used under severe environments, it may be desirable to use shorter recalibration intervals.

In some cases, it is desirable to recalibrate in the laboratory or field prior to start of extensive tests. Cost of performing shock or vibration tests is frequently quite large and not repeatable. In these cases, calibration just prior to conducting the test is warranted, particularly if history of previous usage of the accelerometer is not well known. If calibration facilities are not available, accelerometers may be returned to Endevco for recalibration at a nominal charge. See Calibration Service Bulletin No. 301.

It is recommended that those laboratories conducting important tests acquire accelerometers to be used solely as reference accelerometers. The Endevco® Model 2270 Primary Standard Accelerometer is a stable and convenient reference for checking the calibration of working accelerometers.

Accelerometers exhibiting characteristics not correctable in the field should be returned to Endevco for repair. Repair charges are nominal and usually include the incorporation of any new design technique into the earlier models, bringing their specifications up to those of the latest units.

4.3 Cable Maintenance

Endevco does not repair any subminiature coaxial cables after initial failure. It is felt that these cables, once they have failed, are no longer reliable and should be replaced from our stock of new and calibrated cables.

4.4 Warranty

Endevco warrants each new piezoelectric transducer to be free from defects in materials and workmanship. This warranty applies, from date of sale to the original purchaser, for a period of 1 year for the 5200 Series accelerometers, 2 years for the 6200 Series accelerometers, and 3 years for piezoelectric transducers in the 2200 Series (acceleration) and 2500 Series (pressure). This warranty does not extend to units that have been misused or used in violation of Endevco recommendations, or to units that have been altered or repaired outside Endevco's factory. Defects covered by this warranty will be remedied at no charge, provided this instrument is delivered to the factory with all transportation charges prepaid. If, upon examination, it is found that the defect is not within the scope of this warranty, a statement of repair charges and a request for authorization to proceed with repair will be submitted.

The above warranty period does not extend to new cable assemblies, mounting accessories, connectors and other non-serialized products which are only warranted to meet applicable Endevco specifications when shipped from our factory.

The liability of Endevco under this warranty is limited to repair or replacement of any defective instrument within the sole discretion of Endevco. The foregoing warranty is exclusive and in lieu of all other warranties expressed or implied.

4.5 Return of Equipment

Ship all instruments, regardless of warranty, with all transportation charges prepaid, to:

Service Department
Endevco
Rancho Viejo Road
San Juan Capistrano
California 92675

A statement describing the fault noted should accompany the shipment.

ENDEVCO® CALIBRATION SERVICE

Endevco provides a service for calibration of transducers, electronics and systems. Periodic recalibration is recommended for these instruments to verify product function, quality and calibration. The calibration methods used and results obtained in this service are in accordance with approved standards of the American National Standards Institute, Department of Defense Specification MIL-STD-45662, and the Instrument Society of America. All calibrations are traceable to the National Bureau of Standards.

Any piezoelectric or piezoresistive accelerometer weighing less than two ounces can be calibrated. Unless otherwise instructed, the calibrations of piezoelectric accelerometers are performed with charge amplifiers in terms of picocoulombs per g. The voltage sensitivity applicable at a single frequency is also reported. If the accelerometer is normally used with voltage amplifiers, the particular amplifier and input cable of intended use should be submitted; otherwise, the cable and amplifier capacitance and load resistance should be specified. If these are not specified, the requested voltage calibrations will be performed with a 1000 MΩ load and 300 pF external capacitance.

Calibration services include Shock Calibration (No. 1), Reciprocity Calibration (No. 2), and Sinusoidal Comparison Calibration of sensitivity and frequency response (No. 3). The results of these three services are furnished in a comprehensive report. Traceability to the National Bureau of Standards is shown as required by military quality control procedures. Each Endevco calibration service includes the measurement of accelerometer sensitivity at a single frequency, capacitance and/or resistance, and maximum transverse sensitivity. Supplemental calibrations of Amplitude Linearity (No. 4), Temperature Response (No. 5) and Low Frequency Response (No. 9) are also available.

Calibration service numbers 1 through 5 and 9 are available for individual accelerometers, or systems including accelerometers, cables and amplifiers, at no additional cost. They may be of anyone's manufacture. Calibration services for Systems (No. 6), Transducers (No. 7), and Electronics (No. 8) are offered only for instruments manufactured by Endevco.

NO. 1 SHOCK CALIBRATION

	No. 1A and No. 1B	No. 1C
SHOCK RANGE	20 g to 10 000 g, ±10%	10 000 g to 100 000 g, ±20%
DURATION	30 ms at 20 g to 150 μs at 5000 g 200 μs at 10 000 g	200 μs at 10 000 g to 80 μs at 100 000 g
SHAPE OF PULSE	Half-sine	Half-sine
NUMBER OF LEVELS	3 different applied accelerations which may be selected by customer	1 test at 10 000 g using 2270 acceleration standard; and 3 other different applied accelerations, which may be selected by customer
UNCERTAINTY OF CALIBRATION	< ±3.2%	< ±6%
CALIBRATION TECHNIQUE	Comparison of peak acceleration using 2270 accelerometer standard	Comparison of accelerometer velocity using strain gages on the Compression Wave Shock Calibrator (Ref. Endevco TP 284)
DATA SUPPLIED	Comprehensive Report, figures showing waveforms	Comprehensive Report, figures showing waveforms, zero shift at highest acceleration level
EXCITATION Below 5000 g Above 5000 g	2965C Comparison Shock Calibrator Compression Wave Shock Calibrator	Compression Wave Shock Calibrator
FREQUENCY RESPONSE DATA	For those accelerometers with adequate sensitivity, a swept-sine plot of normalized sensitivity expressed in dB units is provided to indicate the resonant frequency and/or any local resonances up to 50 000 Hz. A plot of phase angle at frequencies up to 10 000 Hz is provided if phase is significantly different from zero degrees. For accelerometers with very low sensitivity, the resonant frequencies are determined by a transient method and reported with no plot.	

*No. 1B is performed in conjunction with No. 2 or No. 3, which includes frequency response plot.

SINUSOIDAL CALIBRATIONS

NO. 2 RECIPROCITY CALIBRATION
NO. 3 COMPARISON CALIBRATION

Reciprocity calibration (No. 2) is provided only for accelerometers of Primary Standard quality, such as the Endevco 2270, either alone or combined with the charge amplifier with which it is to be used. The system calibration is performed with an external load of 100 KΩ minimum, unless a different load is specified. Reciprocity is performed only at one frequency — 100 Hz — or as customer-selected between 80 Hz and 160 Hz. The comparison calibration described below is also included as part of the No. 2 calibration. Additional amplifiers, such as 2710FM14, which may be part of a complete calibration system, are not included in this calibration — see Electronics No. 8.

Comparison calibration (No. 3) is provided for general purpose accelerometers and for systems. The comparison is made to an Endevco Model 2270 Primary Standard Accelerometer with a point-by-point sensitivity plot provided between 5 and 10 000 Hz at frequencies which can be selected by the customer.

ENDEVCO
World Headquarters 30700 Rancho Viejo Road San Juan Capistrano CA 92675 USA (714) 493-8181 Telex 68-5608 TWX 910-596-1415

	No. 2 Reciprocity Calibration and Frequency Response	No. 3 Comparison Calibration and Frequency Response
UNCERTAINTY OF CALIBRATION	100 Hz (by Reciprocity) - < ±0.5% 5 to 2000 Hz - < ±1.1%* 2000 to 10 000 Hz - < ±2.1%*	100 Hz - < ±1.0% 5 to 2000 Hz - < ±1.5% 2000 to 10 000 Hz - < ±2.5%
FREQUENCY RANGE	5 to 10 000 Hz	
AMPLITUDE RANGE	5 to 25 Hz - up to 0.3 inch double amplitude 25 to 10 000 Hz - up to 10 g	
EXCITATION	Electrodynamic Shaker	
DATA SUPPLIED	Comprehensive Report, a plot of ten point-by-point frequency responsive measurements, a swept-sine plot of normalized sensitivity expressed in dB units to indicate the resonant frequency and/or any local resonance up to 50 000 Hz, and plot of phase angle vs frequency to 10 000 Hz (only if phase is significantly different from zero degrees).	

*Applies only for "back-to-back" accelerometers such as Endevco 2270. For general purpose accelerometers, the Uncertainty of Calibration is shown in No. 3 Comparison Calibration and Frequency Response.

NO. 4 VIBRATION AMPLITUDE LINEARITY CALIBRATION

Calibration is provided at five vibration levels from 1 to 100 g peak at a single frequency within the rated frequency range of the accelerometer. Sinusoidal excitation is by means of an electrodynamic shaker equipped with a resonant beam. This calibration is available only as an addition to No. 2 or No. 3 and the results are included in a combined report.

NO. 5 TEMPERATURE RESPONSE CALIBRATION

When ordered with calibration service numbers 1, 2, 3 or 7, Temperature Response Calibration is performed within the range of −300° F to +1400° F (−184° C to +760° C) at a single frequency within the rated frequency range of the accelerometer.

Unless otherwise specified in the purchase order, Endevco accelerometers are calibrated at the temperatures listed on the applicable data sheet (Calibration No. 5A). For any accelerometer, temperatures may be selected by the customer (Calibration No. 5B). If the device is not manufactured by Endevco, its survival must naturally be the responsibility of the customer. Calibration data is recorded in the Service Report or Certificate provided with the service ordered along with this request.

NO. 6 SYSTEM CALIBRATION

Calibration service is provided for acceleration and sound measuring systems including an accelerometer or microphone and its signal conditioner. This service applies only to products manufactured by Endevco. The systems are usually identified with a five digit model number.

The calibration includes application of a dynamic measurand (sinusoidal vibration, shock motion, or sound) to the transducer and setting the amplifier gain (except for amplifiers with fixed gain) to obtain a specific system sensitivity. System sensitivity is the ratio of electrical output of the amplifier to the applied measurand. Sensitivity should be specified by the customer. The calibration is performed at room temperature and at a single frequency and/or a single amplitude of the measurand. The value of system sensitivity is provided.

NO. 7 TRANSDUCERS

Recalibration service is provided only for Endevco piezoelectric and piezoresistive transducers (no separate electronics). The calibration data supplied are listed on the specification sheet for each model. Data is provided on a calibration certificate.

For most linear accelerometers, these calibrations include: sensitivity, capacitance or resistance, maximum transverse sensitivity, and frequency response. Unless otherwise specified, piezoresistive transducers are calibrated with an applied excitation of 10.0 volts dc.

For most angular accelerometers, pressure transducers and microphones, these calibrations include at least sensitivity and capacitance or resistance.

NO. 8 ELECTRONICS

Endevco electronic products are calibrated and certified for compliance to published specifications. If repair is required, a statement of repair charges and a request for authorization to proceed will be submitted.

NO. 9 LOW FREQUENCY VIBRATION CALIBRATION

Frequency response calibrations at low frequency are accomplished on a special long stroke vibration exciter by comparison measurements to a servo accelerometer. This service is available by itself or as a supplement to the No. 3 calibration to extend the frequency range.

FREQUENCY RANGE	1 Hz to 30 Hz
ACCELERATION LEVEL	0.25 g pk
EXCITATION	Electrodynamic shaker with 6 in. double amplitude capability
UNCERTAINTY OF CALIBRATION	Less than ±1.5%
DATA SUPPLIED	Report, including tabulation of response vs. frequency
NUMBER OF POINTS	Five different frequencies. These may be selected by customer

NOTES:

1. Calibration is limited to single axis accelerometers. The resonant frequency part of this service may be omitted when calibrating triaxial accelerometers due to limitations in equipment used for mounting the units.
2. Frequency range for triaxial accelerometers weighing more than one gram is limited to a maximum of 2000 Hz.

DELIVERY

Any or all of the above calibrations are usually completed within 3 weeks from receipt of the equipment to be tested, and a purchase order.

SHIPPING INSTRUCTIONS

Please address all inquiries to, and mark all papers "Attention: Service Department." Ship transducers and/or electronics prepaid to Endevco, 30700 Rancho Viejo Road, San Juan Capistrano, California 92675, USA.

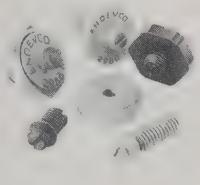
ENDEVCO® ACCELEROMETER MOUNTING EQUIPMENT & ACCESSORIES
2900 Series

Proper mounting counts — whatever your application. From the delicate, virtually "non-contact" measurement of a hummingbird's wing to the ultra-high "g" monitoring of advanced space vehicles. Endevco has been there, and virtually everywhere in between.

To insure the maximum integrity of your data Endevco gives you the broadest array of mounting choices: Hardware — Accessories — Tools. Plus in-depth technical background. In short, all you're likely to need to make the best selection for your particular job, with most all of the trade-offs fairly defined. If you don't find your answer here, your Endevco representative is ready to help you.

MOUNTING STUDS

To ensure the generation of useful, accurate data, an accelerometer must be properly attached to the structure or component under investigation. As a general rule, rigidity of the accelerometer over the frequency range of interest is a prerequisite. Perpendicularity, direct contact, low relative dynamic mass, and compatible temperature with the structure are also desirable characteristics depending on the application. A variety of mounting methods are available which should fit the practical requirements of your system and your cost/performance criteria.



Standard Stud Mounting

Where possible, this is the ideal method of accelerometer mounting. It ensures that the entire accelerometer base is in intimate contact with the test object. The surface of the test object should be flat and smooth. Mounting holes should be perpendicular (±6 minutes). Ordinary machine screws should be avoided because they lack a flange or shoulder. Such screws might "bottom" in the accelerometer, which could change its dynamic response and damage the unit. These studs are detachable, permitting rapid, low-cost replacement, and they are accepted by most Endevco accelerometers.

Insulated Mounting Studs

An Endevco exclusive, these patented, insulated mounting studs provide electrical isolation of the accelerometer from the structure ground. Ideal for elimination of data-destructive ground loops, these insulated studs are vastly superior to other methods of isolation which do not also eliminate effects of stray capacitance from signal lead to ground. Widely accepted and field proven, they are recommended for use when accelerometer case and cable shield are connected to instrumentation ground.

Cementing Studs

Ideal for applications where the test object surfaces cannot be tapped or drilled, or where mounting surface irregularities make flat, rigid mounts otherwise impossible. These studs enable mounting without contamination of the accelerometer mounting threads, which might occur if mounted directly to the test surface. Removal of the accelerometer is also facilitated by this method. A variety of cements for various applications are available. Further discussion of mounting techniques for all studs is covered under the "Mounting And Removal Tools" section.

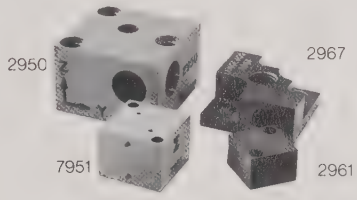
Specifications

DYNAMIC	
RANGE	
Non-insulated studs	To the specified limit of the accelerometer
Insulated studs	2000 g pk shock, with maximum of one ounce load at room temperature
2984M4	5000 g pk shock with 2221 accelerometer
2985	150 g pk, vibration, with one ounce load and temperature range −300° F to +750° F
2983M7/M8	100 000 g pk with 5 gram maximum load
Cementing studs	Determined by adhesive
PHYSICAL	
MATERIAL, Metal	All 400 series stainless steel excepting: 2986B, 17-4PH SS; 2987, 300 series SS; 2988, 2980M9, 2983M7/M8, aluminum.
FINISH	
2981-4, 12802-2	Black oxide
2988, 2980M9	Hard anodize
DIMENSIONS	See Table
MOUNTING TORQUE	See Application Notes
INSULATION RESISTANCE	Insulated studs: 10 MΩ, minimum
ENVIRONMENTAL TEMPERATURE	
Non-insulated studs	−450° F to +1000° F (−270° C to +538° C)
2985	−300° F to +750° F (−184° C to +400° C)
2980B, 2980M4, 2983B	−450° F to +500° F (−270° C to +260° C)
2986B, 2986M2	−300° F to +500° F (−184° C to +260° C)
2984M4	−450° F to +350° F (−270° C to +177° C)
2983M5	Depends on adhesive
RELATIVE HUMIDITY	100%

TRIAXIAL MOUNTING BLOCKS

Precise resolution of data in vector coordinates from a single point on your test structure is provided with this array of mounting blocks. Endevco's total design consideration ensures the highest possible frequency response, whatever your application.

Block faces are accurately controlled to achieve virtual orthogonal perfection. This saves both time and high machining costs to make your own triaxial mounting surfaces. The selection of materials is also based on careful consideration of end-use criteria. Berryllium on Model 2967, for instance, provides optimum transmissability. Lightweight magnesium for Model 2961 ensures low dynamic mass, and aluminum for Model 2950 is the obvious best compromise between mass and economy. Whether stud-mounted or adhesive mounted, every characteristic has been carefully and precisely selected in the design of these units to provide you with the most precise, reliable data obtainable.



If the majority of your measurements are triaxial in nature, you may wish to refer to our entire line of triaxial accelerometers for their inherrent reductions in size and weight. The Model 23 triaxial accelerometer, for example, delivers a frequency response of 10 kHz, about 20% more than other units. For complete technical information on this unit, refer to Endevco Model 23 data sheet.

The general principles regarding proper mounting techniques for studs applies to these triaxial mounting blocks.

MOUNTING CEMENTS

The selection of adhesives requires a thorough evaluation of your particular application requirements. In general, the selection of adhesive depends initially on whether your installation is permanent or intended for eventual removal. Other considerations may involve various factors such as high temperature, humidity, or immersion and the quality of the specimen mounting surface.

Removal Mounting

Cyanoacrylate adhesives such as Aron Alpha (Vigor Company, New York, N.Y.) are recommended for rapid mounting where subsequent removal is desired. Care in application of these cements is advised to prevent filleting on the sides, since excessive cement can cause damage to the accelerometer during removal.

The accelerometers are easily removed from the structure by softening the adhesive with solvent and rotating to break the bond. Adhesive remaining on the accelerometer or the structure should be removed with an appropriate solvent. Sanding or scraping of accelerometers to remove adhesives is not recommended because this may cause permanent damage to the unit.

Permanent and Semipermanent Installations

The following cements are recommended for this type of application. They are also suitable for use with cementing studs.

Transmount HT Adhesive Film — useful to 400° F.
EPIBOND 1210 — cures at room temperature, useful to 250° F.

SPECIFICATIONS FOR MOUNTING BLOCKS

MODEL	2950	2950M3	2961	2967	7951	7954	7955
For use with:	Accelerometers with 10-32 x .117 inch mounting holes	2221, 7221, 7251	2222B Accelerometer	2255, 2291 or 2292 Accelerometers	2264-150 2264-4500 Accelerometers	7264	7265A
Size: inches (millimeters)	1.00 x 1.00 x 0.67 (25.4 x 25.4 x 17.0)	0.875 x 0.875 x 0.625 (32.2 x 22.2 x 15.9)	0 42 x 0.42 x 0 29 (10.7 x 10 7 x 7 4)	0 86 x 0 86 x 0 37 (21 8 x 21 8 x 9 4)	0 56 x 0 56 x 0 43 (14 2 x 14 2 x 10 9)	0 58 x 0 58 x 0 43 (14 7 x 14 7 x 10 9)	0 80 x 0 80 x 0.66 (20 3 x 20 3 x 16 8)
Material:	Aluminum	Aluminum	Magnesium	Beryllium	Magnesium	Magnesium	Magnesium
Finish:	Grey Anodize	Anodize	Dow #17	None	None	None	None
Weight: (nominal)	30 grams	20.5 grams	1.2 grams	5.1 grams	4.5 grams	4.5 grams	12 grams
Mounting: Accelerometer	Clearance holes for three 10-32 socket head screws	6.32 x .312 holes for three accelerometers.	Adhesive	1/4-28 x 0 250 holes for three accelerometers	0-80 x 0 150 holes for three accelerometers	0-80 x 0 150 holes for three accelerometers	2-56 x 0 100 holes for three accelerometers
To structure	Holes for three insulated 4-40 screws, insulated mounting pad. 2950M5 for 10-32, non-insulated.	Clearance holes for two 4-40 screws.	1 Adhesive 2. Clearance holes for two 0-80 screws. 3. 10-32 x 0.130 inch hole.	Clearance holes for two 10-32 screws.	Clearance holes for two 2-56 socket head screws.	Clearance holes for two 2-56 screws	Clearance holes for two 4-40 screws
Accessories Supplied:	1. 3 each 10223 insulated 4-40 x 7/8 socket head screws. 3 ea EH472 10-32 x 7/8 with 2950M5 2. 3 each 10-32 socket head screws.	1. 2 each 4-40 x 7/8 socket head screws. 2. Hex wrench	1 2 each 0-80 x 5/16 socket head screws 2. Hex wrench 3. 2981-3, 10-32 mounting stud.	2 each 10-32 x 3/8 socket head screws	1 2 each 2-56 x 9 16 socket head screws 2 6 each 0-80 x 3/16 socket head screws. 3. 2 hex wrenches.	1 2 each 2-56 x 9/16 socket head screws 2 6 each 0-80 x 3/16 socket head screws. 3. 2 hex wrenches.	1 2 each 4-40 x 3/4 socket head screws 2 6 each 2-56 x 3/16 socket head screws 3. 2 hex wrenches.

SPECIFICATIONS FOR MOUNTING STUD ADAPTERS

MODEL / DIMENSIONS	NON-INSULATED								INSULATED									CEMENTING STUDS	
	2981-1	2981-3	2981-4 (metric)	2984-1	2984-2	2984M3	12802-1	12802-2 (metric)	2980B	2980M4	2980M9	2983B	2983M7/ M8/M9	2984M4	2985	2986B	2986M3 (metric)	2987	2988
A Thread. 1. Structure 2. Accelerometer	10-32 10-32	10-32 10-32	M5 x .8 10-32	1/4-28 10-32	1/4-28 1/4-28	10-32 6-32 (hole)	10-32 10-32	M5 x .8 10-32	10-32 10-32	10-32 10-32	190 UNR-3A	1/4-28 10-32	1/4-28 ★ 1/4-28 (hole)	10-32 6-32 (post)	10-32 10-32	10-32 10-32	M5 x .8 10-32	—— 6-32 (hole)	—— 10-32
B Over-all Length (reference)	.623 (15.8)	.400 (10.2)	.400 (10.2)	.385 (9.8)	.434 (11.02)	.500 (12.8)	.710 (18.0)		714 (18.1)	.474 (12.0)	.594 (15.09)	714 (18.1)	.470 (11.94)	.845 (21 4)	.540 (13.8)	.506 (12.9)		.187 (4.74)	.245 (5.49)
C Stud Length, Structure End	.480 (12.1)	.257 (6.52)	.257 (6.52)	.250 (.64)	.257 (6.53)	.250 (6.53)	.490 (12.4)		.490 (12.4)	.250 (6.35)	.300 (7.62)	.490 (12.4)	.170 (4.32)	.250 (6.35)	.250 (6.35)	.250 (6.35)		——	——
D Flange Thickness	.020 (.50)				.022 (0.56)	.250 (6.35)	.104 (2.64)		.104 (2.64)		.294 (7.47)	104 (2.64)	.270dp Hole	020 (508)	.175 (4.44)	.141 (3.58)		.187 (4.74)	.125 (3.17)
E Flange Diameter	.240 (6.09)				.300 (7.62)	1/2 hex (12.7)			.495 (12.5)		5/8 hex (15.9)	495 (12.5)	1/2 hex (12 7)	312 (7.92)	5/8 hex (15.9)	5/8 hex (15.9)	14 mm hex	1/2 hex (12.7)	1/2 hex (12.7)
F Slot, .030" x .040" deep	BOTH ENDS					NONE			ACCELEROMETER				NONE	A2					

'gh Humidity, Immersion, Rough Surfaces

ental cements are particularly suited to these types of situations. We enerally recommend Grip (L.D. Caulk Company, Milford, Delaware).

OUNTING AND REMOVAL TOOLS

'hether mounting or removing Endevco accelerometers, it is essential to ilize proper techniques and tools. Correct torque is essential to ensure rrect mounting and subsequent performance. When removing a unit, oper torque with Delrin sockets guards against damage. Instruction anuals are available with all units.

he following mounting and removal tools are recommended for use with ll Endevco accelerometers. With the exception of the sockets, the balnce of the tools are supplied with each accelerometer. They are listed ere for your convenience in re-ordering or replacement.

940	⅝" drive socket, hexagonal, Delrin. For mounting Endevco accelerometers with ⅝" hex base and side connectors.
941	Removal Tool, Delrin. For Model 2220C, 2226C and 2229C accelerometers.
943A	Removal Tool, Delrin. For Model 2222A and 2222B accelerometers.
17267	Removal tool, anodized aluminum. For removal of Model 22 accelerometer and accelerometer cable.
18060	Removal tool, anodized aluminum. For removal of Model 23 triaxial accelerometer and accelerometer cable.
22114	Removal tool, anodized aluminum. For removal of Model 2250A accelerometer and accelerometer cable.

APPLICATION NOTES

Mounting Torques

To ensure damage-free, proper mounting and repeatability of measurement, the accelerometer should be tightened to the value given in the table below:

Stud Thread	lb-in	kg-cm	Nm
2-56	5	6	0.6
4-40	8	9	0.9
6-32	10	12	1.2
10-32	18	20	2.0
¼-28	24	27	2.7
M5×0.8mm	18	20	2.0

Surface Characteristics

Mounting surfaces and tapped holes should correspond to the following specifications in order to ensure proper operation of stud mounted accelerometers.

Surface flatness	0.0003" TIR
Surface roughness	32 micro inch rms
Hole perpendicularity	±6 minutes
Thread class	1

For 5000 Hz or higher, and/or shock pulse durations, apply a drop of light oil between mating surfaces to prevent degradation of the frequency response.

Facilitating Stud Removal

In steel test fixtures, application of oil to stud threads is suggested. This will tend to facilitate removal and avoid binding, seizing or galling of the stud with the test fixture's internal thread.

In aluminum fixtures, application of anti-seizing compound is recommended. Caution is urged to avoid application to mounting surfaces in order to avoid adverse effects to the high frequency response. Special caution is urged for use with insulated mounting studs. Conductive lubricants should not be allowed to creep across the flange insulating layer.

Mounted Resonance Frequency Of Insulated Studs

The use of an insulated stud will result in a reduction of the mounted resonance frequency of 15 to 30% compared to standard studs. The flat frequency response range is correspondingly reduced by the same factor.

Pressure Sensitive Tape Mounting

Effective mounted resonance frequencies will be lower than those obtained with stud mounting. The use of plastic or insulated blocks will similarly affect resonance frequencies. For measurement of vibration above a few hundred Hz, a critical analysis of resonance frequency reduction is recommended.

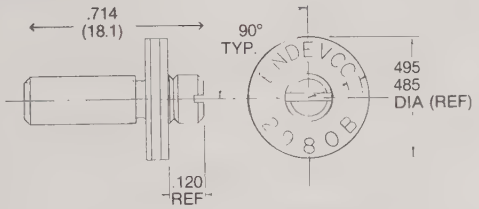
Hand-Held "Probes"

Data obtained in this manner should be regarded as merely approximate and are limited to low frequencies. The force required to hold a hand-held probe in intimate contact with the surface of the test structure may affect the structure motion sufficiently to invalidate the data.

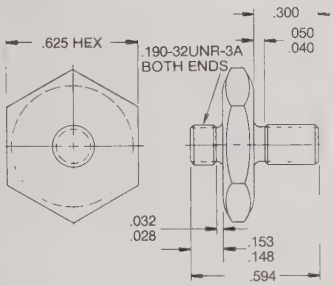
DRAWINGS

MOUNTING STUDS

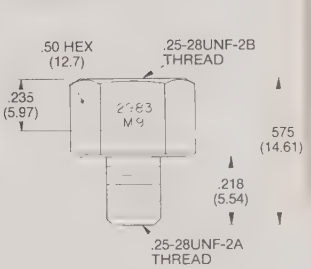
2980B



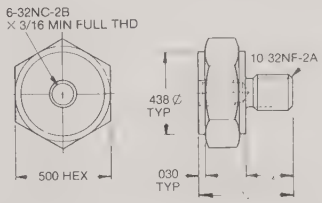
2980M9



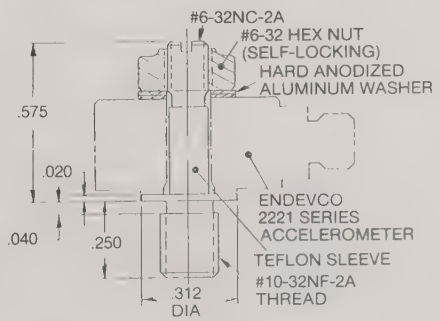
2983M9



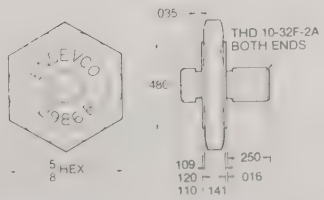
2984M3



2984M4



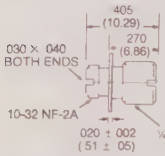
2986B



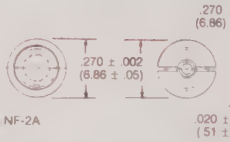
NOTE: Mounting studs may be used with any ENDEVCO accelerometer having the indicated mating thread. Special studs and adapters include:
2983 Series for Models 2291 and 2292 accelerometers
2984 Series for Model 2221
2985 for high temperature use with Model 2273A

ADAPTERS for Model 2270

15071 — Mounting Stud



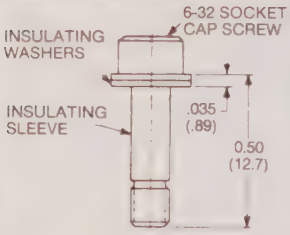
14159-X — Adapter Bushing
(for mounting test accelerometers)



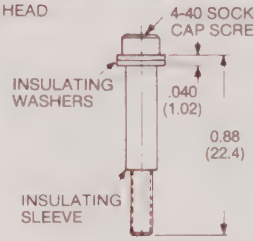
-X	G THREAD
-1	10-32 NF
-2	6-32 NC
-3	4-40 NC
-4	2-56 NC
-5	4-48 NF
-6	8-32 NC

INSULATING MOUNTING SCREW ASSEMBLIES

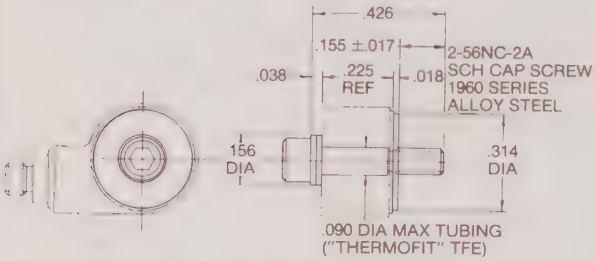
10207 — for Model 2221



14891 — for Model 2223D

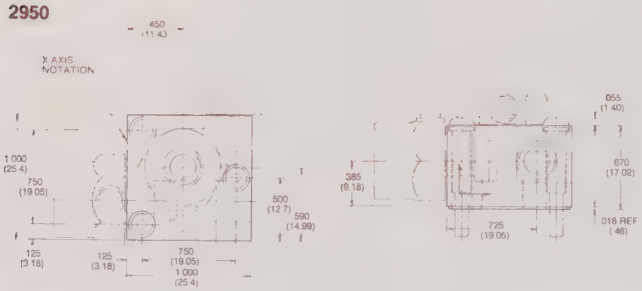


12746 — for Model 2220

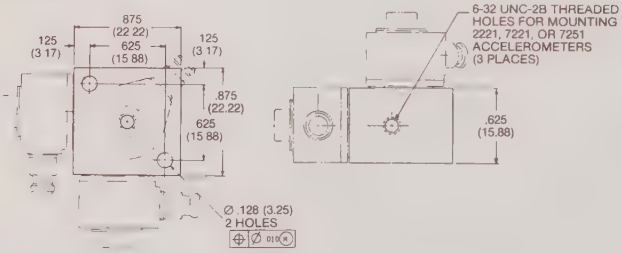


MOUNTING BLOCKS

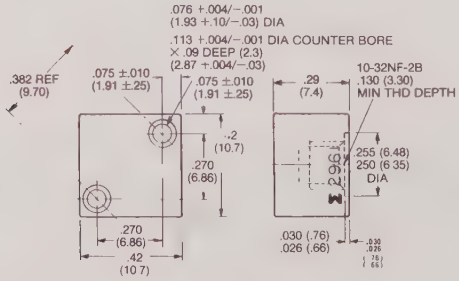
2950



2950M3

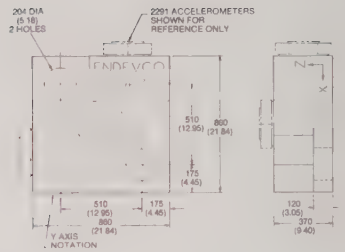


2961

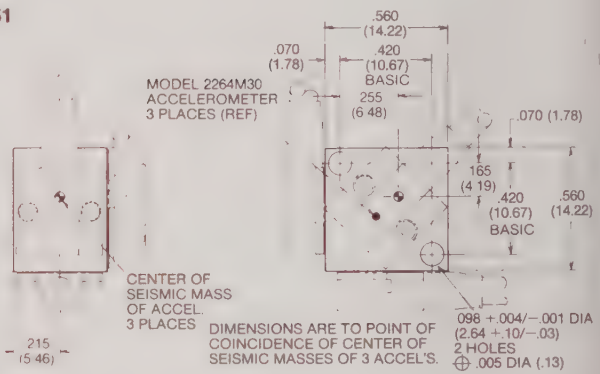


Dimensions are shown in inches (millimetres)

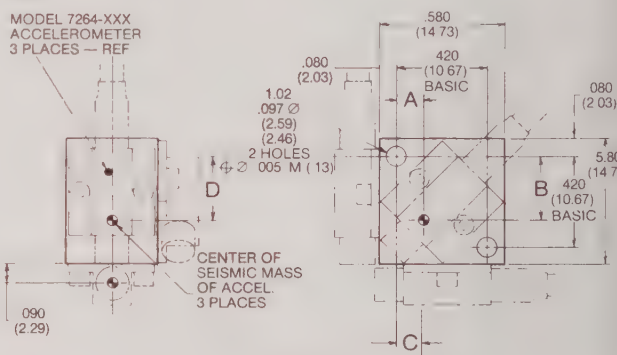
2967



7951



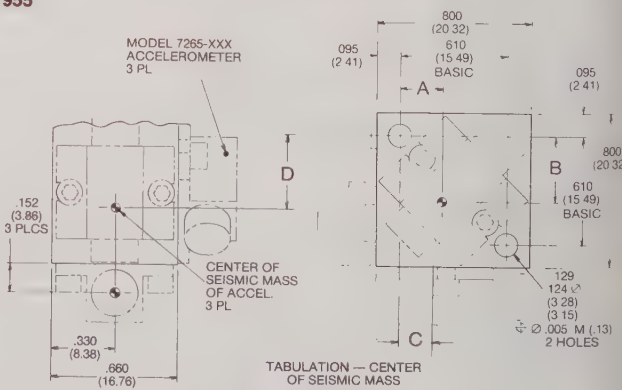
7954



TABULATION — CENTER OF SEISMIC MASS

ACCEL. MODEL NO.	A	B	C	D
7264-200	.125 (3.18)	.295 (7.49)	.125 (3.18)	.295 (7.49)
7264-2000	.033 (.84)	.387 (9.83)	.005 (.13)	.425 (10.80)
7264-5000	.055 (1.40)	.365 (9.27)	.025 (.64)	.395 (10.03)

7955



TABULATION — CENTER OF SEISMIC MASS

ACCEL. MODEL NO	A	B	C	D
7265-10	.213 (5.41)	.397 (10.08)	.193 (4.90)	.417 (10.59)
7265-20 7265AHS	.263 (6.68)	.347 (8.81)	.263 (6.68)	.347 (8.81)
7265-50	.259 (6.58)	.351 (8.92)	.258 (6.55)	352 (8.94)
7265-100 7265A	224 (5.69)	.384 (9.75)	.210 (5.33)	.400 (10.16)

TABULATION DIMENSIONS ±.030 (±.76)

ENDEVCO® CABLE GUIDE
3000 SERIES

THE CABLE - AN IMPORTANT LINK

The transducer cable assembly, connecting a transducer to an amplifier or signal conditioner, is an important link in a data acquisition system. It must transmit the signal without signal loss and spurious effects, and must operate in the same environment as the transducer.

Recognizing these requirements, Endevco has continued to design, test and improve cables and connectors for transducer cable assemblies. For example, Endevco has developed and built a continuous cable noise tester. Every inch of the cables described in this data sheet and marked with an asterisk (*) is tested in this machine.

THREE COMMON MISCONCEPTIONS ABOUT CABLE

For over 30 years, Endevco has helped solve dynamic instrumentation problems. That's why the name Endevco and the stylized "E" have become a dynamic status symbol. That's also why we are especially interested in keeping your measurement system free of avoidable trouble. Since cable is a frequent — and frequently misunderstood — source of unnecessary problems, we offer this information to help you make the best choice of cable for your present needs.

MISCONCEPTION NUMBER ONE:
"Cable is Cable. It's All Pretty Much Alike."
Wrong on two counts.

First, no two lengths of cable have exactly the same noise characteristics. In fact, we often find variations between adjacent sections from the same parent reel.

Second, and equally important, cable specifications are not all alike. You can't compare one manufacturer's specifications against another's unless you know the test procedures employed by each.

The standard test, used for ISA RP37.2 specs, is based on a relatively simple procedure. A weight is attached to a known length of cable; the weight is dropped a prescribed distance; the charge generated by the resultant flexing is measured.

There are some pretty apparent limitations to that method. For one thing, it isn't highly repeatable. So, the usual practice is to make several drops and settle for the average result. For obvious reasons, drop testing is generally performed on only the end-sections of each reel, leaving the hundreds of feet in the center untested.

We have a different approach. Because we know that cable varies inch-by-inch, we have developed unique, 100% continuous testing equipment that repeatedly flexes each inch of cable under prescribed tensions, producing accurate, repeatable results.

Our method can be correlated with TP37.2, if you keep in mind that it is more stringent by a factor of 7. For example, our specification of 1.5 pC pk-pk maximum per Endevco QCP 28-13-142 for the 3090C cable is approximately equivalent to an RP37.2 rating of 0.22 pC. The only difference is that Endevco spec is guaranteed for every inch of cable.

We don't have to be that tough on our cable assemblies. We don't have to give you handwritten certification of the capacitance of each length of Endevco cable. We do it because cable performance affects the performance of our accelerometers and instrumentation. It isn't that we're heroes; it's just that we've built our business by doing things right.

MISCONCEPTION NUMBER TWO:
"Ready-Made Assemblies Are An Extgravagence. It's More Economical to Buy Quality Cable in Bulk and Make Your Own Assemblies."
Please, don't. Our primary business is accelerometers and instrumentation. Nonetheless, we advise strongly against making your own cable assemblies. Why? For the same reason we have established a painstaking, full-time assembly fabricating operation: because a not-quite-right cable assembly can wreak havoc with the data you get from even the most reliable system components.

Admittedly, if you're able to purchase tools and equipment equivalent to ours, and if you're able to spend the necessary man-hours developing comparable skills and procedures and experience, you can achieve comparable results.

Here is what we mean by comparable results: capacitance-rated assemblies, tested under worst case conditions with specialized test equipment; fabricated by experienced, full-time assemblers using tools specially designed for the purpose; subjected to strict quality assurance inspections by a technical group whose sole concern is the continuing study and evaluation of cable assemblies.

Unless you can make that level of commitment to the task, please don't make your own assemblies. Any apparent saving will be paid back several times over, when you can least afford it, in down-time and lost data.

MISCONCEPTION NUMBER THREE:
"Pin Pull-Out and Contamination Are Just About Inevitable, When You Use Miniature Coaxial Cable."
They are not inevitable at all. Endevco assures a good moisture and contamination barrier and mechanical bond between pin and connector shell by means of a fired glass insulator. You'll find it in the Hi Rel stainless steel connectors on our 3090C cable assembly. It solves traditional problems of pin pullout and intermittent contact. Particularly important in high g studies, it prevents pins from pulling loose and jamming in the accelerometer receptacle.

The 3090C features an improved strain relief which minimizes damage to the cable at the connector under high vibration and high shock conditions. The connector is corrosion-proof and temperature rated from −423° F to +500° F. Which is one more good reason for controlling costs by not trying to make your own cable assemblies.

This Guide includes specificaitons and ordering information for the most widely used Endevco cable and accessories. The accompanying notes are designed to help you select the particular type of cable best suited for each application. We have also included a checklist of methods for reducing the risk of cable-caused data loss.

Our continuing research and development program in dynamic testing includes cable technology, as well as ongoing study of accelerometers and instrumentation. Please contact us if you would like further information on any of these areas.

GUIDE FOR SELECTING THE RIGHT CABLE FOR YOUR APPLICATION

Coaxial Softline Cable Assemblies

3090C Cable: High reliability cable. A premium, general purpose cable designed specifically for use with piezoelectric accelerometers in severe environments where maximum reliability is essential and where repeated usage is an important criteria. Stainless steel connectors, stranded-wire center conductor for maximum flexibility, and high cable pullout tensile strength provide increased ruggedness and long-term life. Connector design features make the cable an excellent choice for high humidity, high temperature conditions. The fused Teflon jacket of the 3090C is recommended in applications where cable abrasion will be encountered. Temperature rated from −423° F to +500° F, the cable also has guaranteed low noise characteristics: 1.5 pC pk-pk maximum. For use with all transducers with 10-32 receptacles. Supplied as standard with ISOBASE and ISOSHEAR accelerometers.

3060A Cable: General purpose cable. High flexibility. Low noise. Silicone rubber jacket maintains high flexibility when operating at low temperature. Same low noise characteristics as 3090C (1.5 pC pk-pk max.). Furnished as standard on 2226C, 2228C and 2229C. Not recommended if cable abrasion will exist. Not recommended for hard vacuum because of outgassing. Usable temperature range: −100° F to +500° F.

3070 Cable: Specialized coaxial cable for use in temperatures over +500° F where cable flexibility is important. Outer jacket is stainless steel braid and is signal ground. Dielectric is made of refractory fiber material. Does not have provision for reduction of triboelectric noise. When the accelerometer is electrically isolated from the specimen by use of an isolated stud, means should be provided to prevent any electrical contact between the cable shield material and the specimen. Cable should not be used in environments that contain higher than 75% RH.

3091D Cable: Specialized coaxial cable. For use with miniature accelerometers — Endevco's 2220C and 2292. Outside cable diameter is only 0.060 inch. Has excellent noise characteristics: 2.5 pC pk-pk max. Temperature range is from −300° F to +350° F. 3091D has a stainless steel 10-32 male plug at one end and a 6-40 connector at the other to mate with the small accelerometers. For longer lengths, attach 3060A or standard 3090C cable with EJ34 adapter.

3093 Cable: Specialized coaxial cable for use with small Endevco 2222C accelerometer. Outer diameter is 0.060 inch. Noise characteristics: 2.5 pC pk-pk max. Temperature range is −300° F to +350° F. May also be used with PICOMIN Model 22, in conjunction with 3003 cable, when a 10-32 female plug is preferred.

3095A Cable: Specialized coaxial cable for use with PICOMIN Model 22 in conjunction with 3003 cable. One end mates with 3003 and the other is terminated with an EP159 10-32 male plug. Jacket is fused Teflon. Temperature range is −100° F to +350° F. May also be used with 2222C when a 10-32 male plug is preferred.

3006 Cable: Small diameter, light weight coaxial cable for Endevco's ISOTRON 2250A-10 microminiature accelerometer with internal charge converter. One end has mating connector for 2250A-10. Other end has Hi Rel 10-32 male plug. Does not require noise treatment because transducer output impedance is very low. Temperature range is −65° to +257° F.

3007 Cable: Heavier duty cable assembly, similar to 3006. Has 5-44 connector for Endevco's ISOTRON Model 2251A miniature accelerometer.

Twisted Pair Softline Cables

3024, 3024M1 Cables: Twisted pair cables for use with ISOTRON accelerometers having solder pin connections. M1 version has shield and jacket. Leadwires are pre-tinned at the transducer end and terminated in 10-32 plug at other end. Red lead to center pin and black lead to connector body.

Coaxial Hardline Cable Assemblies

3075M6 Cable: For very high temperature use to +900° F (+482° C). Has fiberglass jacket over extruded stainless steel sheath, 0.070 in. diameter. Jacket prevents inadvertent grounding. Relatively high cable stiffness minimizes noise if properly tied down. 10-32 plug each end, with safety wire holes. Typically used with 7717, 2276 and 2273 Series.

APPLICATION NOTES

To help the user of these cables and assemblies Endevco makes the following recommendations:

1. When attaching a coaxial cable assembly to a transducer always turn the connector nut onto the transducer. Turning the transducer into the cable connector may damage the pin, the cable or the transducer.
2. Always tie down the cable within 2 or 3 inches of the transducer. Whipping of the cable will generate cable noise, strain the cable unnecessarily at the connector, and cause spurious signals in strain sensitive transducers
3. Always be certain that the cable connector is screwed finger tight, or to specifications, onto the transducer. Do not lose expensive data because of a loose connector.
4. When testing in a high humidity environment, curl the cable into a drip loop near the transducer. Any condensation that occurs will then be drawn away from the connector.

   Apply Dow-Corning Silastic 732 RTV adhesive/sealant (Endevco P/N EHX 214) to connector threads and outer joints to prevent moisture from entering the connector.
5. Keep cable connectors and transducer receptacles clean by dipping them in a volatile solvent before use. Freon, acetone, chlorothene, or similar solvents may be used. Connector contamination caused by ordinary handling can create low impedance paths between signal and ground, increasing noise and affecting the low frequency response of the connected amplifier.
6. If you encounter an intermittent signal and suspect the cable, check the transducer-cable interface. Flex the cable all along its length, particularly near the connector, and observe the effect on the signal. Check center conductor and cable shield continuity with an ohmmeter.
7. Replace noisy cable with Endevco 100% tested low noise cable assemblies. The cost of a reliable, low noise cable assembly is considerably lower than the cost of time and data lost in an important test.
8. If you make your own connector-coaxial cable assemblies, cut the cable carefully. Don't smear the electrically conductive coating across the dielectric.
9. Don't allow cable to be dropped, contaminated, stepped on or otherwise abused. Treat it as carefully as you would treat your transducer.

GENERAL NOTES

1. Lengths are indicated by a dash number after part number designating inches of length. Example: 3090C-36 is a 3090C cable assembly 36 in. long (0.9 m).
2. All coaxial cable assemblies are marked with actual capacitance in picofarads. Model 3090C cable assemblies are also marked with maximum actual noise in pC pk-pk as measured in accordance with Endevco Quality Control Procedure.
3. Connectors not identified by part number are not available separately.
4. Tolerances on cable assemblies cut for length:
   Softline Cable:
   Up to 12 in. (30.5 cm) ±0.5 in. (1.3 cm)
   13 in. (33 cm) to 36 in. (91.4 cm) ±1.0 in (±2.5 cm)
   37 in. (94 cm) to 120 in. (305 cm) ±2.0 in. (±5 cm)
   Over 120 in. (305 cm) ±2.0 in. (±5 cm) per 120 in. or part thereof.

   Hardline Cable
   Up to 24 in. (61 cm) ±1.0 in. (±2.5 cm)
   25 in. (64 cm) to 72 in. (183 cm) ±2.0 in. (±5 cm)
   73 in (185 cm) to 144 in. (366 cm) ±4.0 in. (±10 cm)
   Over 144 in. (366 cm) ±4.0 in. (±10 cm) per 144 in. or part thereof.
5. On special request, 3090C and 3091D type cable assemblies can be cut for a predetermined capacitance. Tolerance on capacitance of these cables is ±1%, or ±4 pF, whichever is greater.
6. Maximum guaranteed length of any cable is 50 ft. Contact factory for longer lengths of cable assemblies.
7. Maximum Insulation Test Voltage is 100 Vdc.
8. Minimum Bend radius is 10 times cable diameter, except for:

Model 3006	R = 0.12" (3 × dia.)
Model 3070	R = 2.3" (20 × dia.)
Model 3075	R = 0.13" (2 × dia.)

9. Cables with noise specifications marked with an asterisk (*) are tested 100% on a Continuous Vibration Noise Tester in accordance with Endevco Quality Control Procedure.
10. Transducer cable assemblies with modified connectors or special connectors are available.
11. Cable assemblies designed for use in a nuclear radiation environment are available.
12. To get longer cable lengths with 3091D, use standard cable and EJ34 adapter.
13. The EP189 connector used on 3093 coaxial softline cable is female — 10-32 jack — and mates with 10-32 coaxial cable plug.
14. Endurance limit (stress) for 3075M6 coaxial hardline cable is 25 000 psi.
15. Continuous product improvement necessitates that Endevco reserve the right to modify these specifications without notice.
16. 3024 is an unjacketed, unshielded, twisted pair cable assembly; 3024M1 is jacketed and shielded.

CONNECTORS

EP11 Cable plug, coax, 10-32, black neoprene, bend relief. (Use EHM530 crimping tool.)

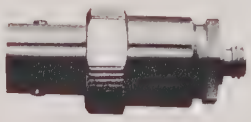
EP189 Cable receptacle, connects to 10-32 coax plug, silicone bend relief.

EP159 Cable plug, coax, 10-32, red silicone bend relief with captive nut. (Use EHM530 crimping tool.)

EJ28 Grounding cap for 10-32 coax receptacles (PE transducers).

ADAPTERS

EP171 Adapts BNC cable plug to 10-32 coax plug.



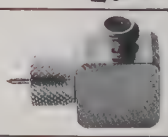
EJ21 Adapts BNC female receptacle to 10-32 coax cable plug.

EJ34 Joins two 10-32 coax cable plugs (EP159).

EJ3 Input signal conditioner, chassis receptacle, coax, 10-32 for ⅛" panels.

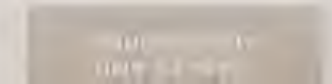
EJ66 Isolated bulkhead feedthru for ⅛" panels. Joins two 10-32 coax cable plugs.

EP310 Right angle adapter, adapts 10-32 coax receptacle (PE accelerometer) to 10-32 coax plug.



Characteristic	Softline Cables									Hardline Cable
Model Number	3006	3007	3060A	3070	3024/3024M1[16]	3090C	3091D	3093	3095A	3075M6
Application	Use with ISOTRON™ Model 2250A	Use with ISOTRON™ Model 2251A Series	High Temperature, High Flexibility	Very High Temperature	Use with ISOTRON™ Model 2250AM1, 2255A, 2255B or 7252 Series	High Reliability, High Humidity, High Temperature, General Purpose	Use with 2220C, 2292	Use with 3003 cable or 2222C	Use with 3003 cable or 2222C	Very High Temperature, High Humidity
Jacket Material	Teflon	Fused Teflon	Silicone Rubber	CRES	None/Extruded Teflon	Fused Teflon	Fused Teflon	Fused Teflon	Fused Teflon	CRES[14]
Bend Relief Material	—	—	Silicone Rubber	—	Molded Rubber	Silicone Rubber	Silicone Rubber	Silicone Rubber	Shrink Tubing	—
Jacket Color	Gold (clear over gold shield)	Red	Red	—	No Jacket/White	Red	Red	Red	Red	—
Outer Diameter, Cable	0.040 in. (1.0 mm) max.	0.060 in. (1.5 mm) max.	0.092 in. (2.5 mm) max.	0.115 in. (2.9 mm) max.	0.065 in. (1.6 mm) max./ 0.104 in (2.6 mm) max.	0.080 in. (2.0 mm) max.	0.060 in. (1.5 mm) max.	0.060 in. (1.5 mm) max.	0.060 in. (1.5 mm) max.	0.070 in. (1.6 mm) max.
Dielectric Material	Teflon	Teflon	Teflon	Refractory Fiber	Teflon	Glass	Teflon	Teflon	Teflon	MgO
Conductor Material	Oxygen-free Copper	Silver Plated Copperweld	Silver Plated Copperweld	Nickel Clad Copper, Ceramic Coated	Stranded, Silver Plated Hi-Strength Copper Alloy	CRES	Copperweld	Silver Plated Copperweld	Silver Plated Copperweld	Nickel
Conductor Size	#36 AWG	#33 AWG	#28 AWG	#25 AWG	#28 AWG (19/40)	#30 AWG (7/38)	#33 AWG	#33 AWG	#33 AWG	#30 AWG
Capacitance per ft	45 pF	30 pF	42 pF	30 pF	9 pF	32 ±3.2 pF	30 pF	30 pF	30 pF	63 pF
Resistance per ft	—	—	0.15 Ω	0.04 Ω	0.066 Ω	0.5 Ω	0.60 Ω	0.60 Ω	0.60 Ω	0.4 Ω
Weight per 1000 ft	1.0 lb	3.3 lb	7.5 lb	10.3 lb	2 lb/7 lb	7.3 lb	3.3 lb	3.3 lb	3.3 lb	8.8 lb
Temperature Range	−65°F to +257°F (−54°C to +125°C)	−65°F to +257°F (−54°C to +125°C)	100°F to +500°F (−73°C to +260°C)	to +705°C (to +400°C)	−300°F to +350°F (−184°C to +176°C)	−423°F to +500°F (−254°C (LH_2) to +260°C)	−300°F to +350°F (−184°C to +177°C)	−100°F to +350°F (−73°C to +177°C)	−100°F to +350°F (−73°C to +177°C)	−300°F to +900°F (−184°C to +482°C)
Temperature Notes	—	—	—	Usable to −450°F (−270°C) under dry conditions	—	Will withstand brief exposures to +650°F (+343°C)	—	—	—	—
Noise, maximum[9]	—	—	1.5 pC pk-pk*	Not treated	—	1.5 pC pk-pk*	2.5 pC pk-pk*	2.5 pC pk-pk*	2.5 pC pk-pk*	—
Endevco P/N Cable	EW702	14065	11121	11188	26269/26271	26108	14065	14065	14065	16170
Standard Connectors	One end mates with 2250A, Hi Rel 10-32 plug other end	One end mates with 2251A, Hi Rel 10-32 plug other end	EP159, 10-32 plug each end	Hi Rel 10-32 plug each end, stainless steel, with safety wire holes	Pretinned conductors at transducer end; 10-32 plug other end	Hi Rel 10-32 plug each end stainless steel with safety wire holes	EP257, 6-40 plug mates with 2220C. Hi Rel 10-32 plug other end	EP189, 10-32 jack one end; other end mates with 3003 cable or 2222C[13]	EP159, 10-32 plug one end; other end mates with 3003 cable or 2222C	10-32 plug each end, with safety wire holes
Standard Length	6 ft (1.8 m)	6 ft (1.8 m)	3, 6, 10, 15, 20 ft (0.9, 1.8, 3., 4.6, 6.1m)	3 ft (.9 m)	10 ft (3.0 m)	3, 6, 10, 15, 20 ft (0.9, 1.8, 3, 4.6, 6.1 m)	6, 10 ft (1.8, 3 m)	12 in. (0.3 m)	6 ft (1.8 m)	3 ft (0.9 m)

All data typical except where otherwise specified * See Note 9



ENDEVCO® MODEL 3090C
HIGH RELIABILITY LOW-NOISE SOFTLINE
Coaxial Cable

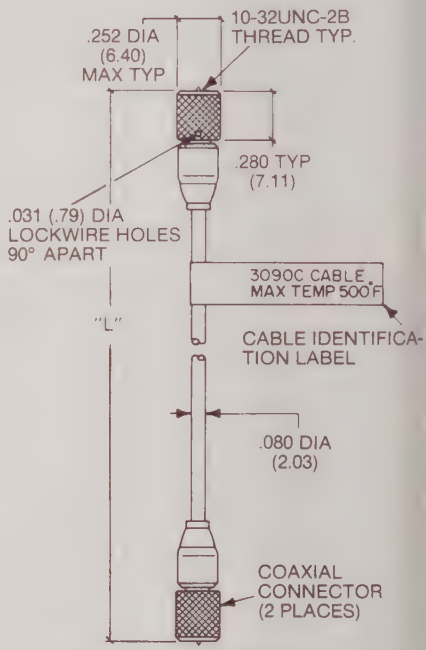
The ENDEVCO Model 3090C is a high reliability low-noise softline coaxial cable. It is a premium general purpose cable designed specifically for use with piezoelectric accelerometers in severe environments. This fused Teflon® jacketed cable has applications where maximum reliability is essential and where repeated usage is important. The cable features (1) stainless steel connectors (center-pin fused into glass insulator, 10-32 threaded nut) with an improved backshell strain relief design; (2) a stranded-wire center conductor for maximum flexibility; and (3) a high cable pullout tensile strength for increased ruggedness and long-term life. Connector design features make the cable an excellent choice for high humidity, high temperature conditions. Temperature rated from −423° F to +500° F, the cable also has guaranteed low noise characteristics. Raw stock cable is tested over 100% of its length on ENDEVCO's exclusive noise tester, using quality control tests proven more severe than noise tests routinely conducted on cable. The fused Teflon jacket of the 3090C is recommended in applications where cable abrasion will be encountered. For those requiring field repair, a kit (EP159) containing a crimp type connector is available.

(All specifications are typical and are for room temperature at approximately 75° F (24° C) unless otherwise specified.)

ELECTRICAL	
CABLE CAPACITANCE	32 ±3.2 pF/ft
CONNECTOR CAPACITANCE	1.5 pF each, typical
DIELECTRIC RESISTANCE	50 GΩ/ft minimum at room temperature
AT 100 Vdc TEST	1 GΩ/ft minimum at 500° F (260° C)
CENTER CONDUCTOR RESISTANCE	0.5Ω/ft, typical
SHIELD RESISTANCE	0.2Ω/ft, typical
PHYSICAL	
CABLE	
Bend Radius	Minimum cable bend radius 0.850 inch (21.59 millimetres)
Conductor Material	Silver-plated annealed copperweld
Conductor Size	Stranded 30 AWG 7/38
Primary Insulation	Teflon, noise treated
Shield	Braided for 90% coverage with 38 AWG silver-plated copper, 16 carriers, 4 wires per carrier
Jacket Material	Red, double tape wrap of fused PTFE Teflon
Weight	3.3 grams/ft, typical
CONNECTOR	
Type	10-32 NF threaded nut with center pin each end (mates with Microdot® S-50 Series receptacles or equivalent)
Pin Material	304L CRES
Dielectric Material	Glass
Connector Housing Material	304 stainless steel
Strain Relief Material	Fluorosilicone rubber
Torque	Finger-tight to 1.5 inch-pounds
EXTERNAL CONFIGURATION	See drawing
ENVIRONMENTAL	
TEMPERATURE	−423° F to +500° F (−254° C [LH_2] to 260° C)
ALTITUDE	Not affected
ACOUSTICAL NOISE	Not affected
TEMPERATURE SHOCK	−300° F to +500° F (−185° C to +260° C) per MIL-STD-810B
VIBRATION	
Noise	1.5 pC pk-pk maximum per Endevco QCP 28-13-142
Random	Per MIL-STD-810B (overall test level 20.7 g rms)
Sinusoidal	1000 g for sustained periods of time 10 000 g maximum
SHOCK	
TENSILE STRENGTH	
Pin Pullout	33 pounds
Cable Pullout	20 pounds typical, 15 pounds minimum
Cable Strength	>20 pounds

LENGTH TOLERANCE TABULATION

LENGTH/inches (millimetres)	TOLERANCE/inches (millimetres)
Up to 12 (304.8)	.50 (12.7)
13 to 36 (330.2 to 914.4)	1.00 (25.4)
37 to 120 (939.8 to 3.05 m)	2.00 (50.8)
Over 120 (3.05 m)	±2.00 (50.8) per 120 (3.05 m) or part thereof



Dimensions in inches (millimetres)

NOTES

[1]Standard lengths: 3, 6, 10, 15, 20 ft (0.9, 1.8, 3, 4.6, 6.1 m). Cable length "L" is indicated by dash number, i.e. 3090C-72 is cable assembly 72 inches long.

[2]Cable length tolerance as shown. For cable assemblies cut for predetermined capacitance, the tolerance is ±1% or ±4 pF, whichever is greater.

[3]Maximum guaranteed length of any cable is 50 ft. Contact the factory for longer lengths of cable assemblies.

[4]All coaxial cable assemblies are marked with actual capacitance in picofarads. Model 3090C cable assemblies are also marked with maximum actual noise in pC pk-pk as measured in accordance with Endevco Quality Control Procedure.

8/85 PS3090C-B

THIS SIDE: 3090C
REVERSE SIDE: 3000 SERIES

Continued product improvement necessitates that Endevco reserve the right to modify these specifications without notice.
Endevco maintains a program of constant surveillance over all products to ensure a high level of reliability. This program includes attention to reliability factors during product design, the support of stringent Quality Control requirements, and compulsory corrective action procedures. These measures, together with conservative specifications have made the name Endevco synonymous with reliability.

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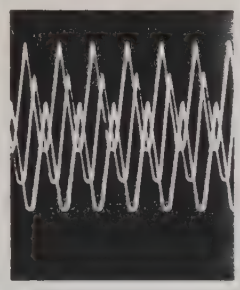
ENDEVCO® TECH DATA



502

VIBRATION NOMOGRAPH

ACCELERATION - g peak

100 μin. | 10 μin. | 1 μin. | 1000 g | 100 g | 10 g | 1 g | 0.1 g | 0.01 g | 0.001 g | 100 μg | 10 μg

DISPLACEMENT - inches peak-to-peak (double amplitude)

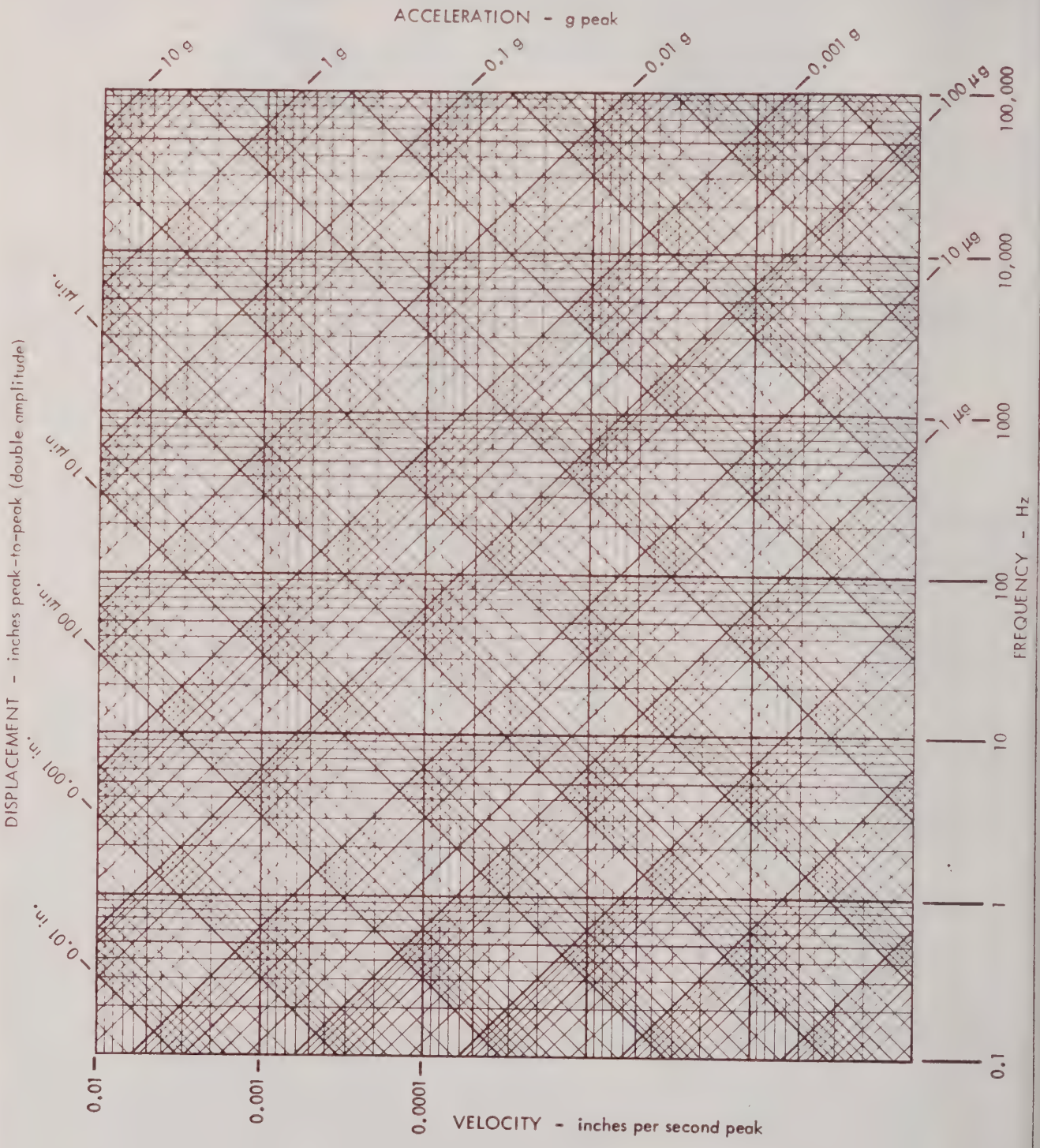
10 in. | 1 in. | 0.1 in. | 0.01 in. | 0.001 in.

FREQUENCY - Hz

100,000 | 10,000 | 1000 | 100 | 10 | 1 | 0.1

VELOCITY - inches per second peak

100 | 10 | 1 | 0.1 | 0.01 | 0.001



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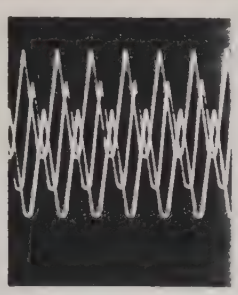

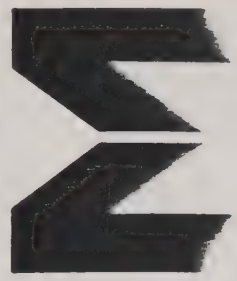

A504

APPLICATION, USE AND REMOVAL OF ARON ALPHA* ADHESIVE CEMENT

The following procedures are recommended for mounting accelerometers with Aron Alpha Adhesive Cement. If the accelerometer is designed for mounting with a replaceable stud, a cementing stud should be used.

MATERIALS REQUIRED

1. Acetone or nail polish remover for use as a solvent.
2. Cotton swabs.
3. Toothpicks or equivalent applicators.
4. Aron Alpha CE-480, #201 Rapid Bonding Adhesive.

SPECIAL PRECAUTIONS

The following precautions should be observed when performing the accelerometer mounting and removal procedures given below.

1. WARNING - Observe precautions recommended by manufacturer of solvent.

2. CAUTION - Exercise care to prevent getting solvent on the accelerometer connector.

3. CAUTION - If accelerometer was designed to accept a stud, and an adhesive mounting stud is not being used, avoid getting cement in the mounting hole.

4. CAUTION - Do not break cement bond by striking accelerometer or by using any tool that makes a metal-to-metal contact with the accelerometer. Always break the bond by twisting or torquing the accelerometer, stressing the bond in shear.

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MOUNTING PROCEDURE

1. Ensure that mating surfaces are smooth and flat.

2. Remove all traces of grease, oil and oily residue from mating surfaces using cotton swabs and solvent.

3. Apply one drop of Aron Alpha to one of the mounting surfaces.

4. Spread the cement with toothpick to form thin, uniform layer covering area of contact, and immediately position accelerometer on mating surface.

5. Press down and hold accelerometer firmly in place for 30 seconds while cement sets. Allow cement to set for at least several minutes for maximum strength.

REMOVAL PROCEDURE

1. Apply acetone or nail polish remover around accelerometer base with cotton swab and wait a short period for cement to soften.

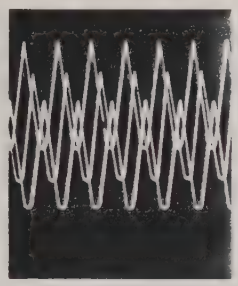
2. Break cement bond, using appropriate Endevco Plastic Socket Wrench to twist or torque the accelerometer, stressing the bond in shear.

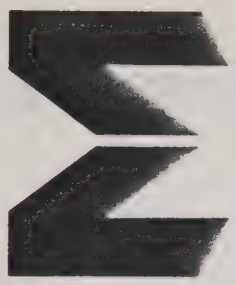
3. Remove cement using a cotton swab dipped in acetone or nail polish remover. A short soak will facilitate this process. Repeat, if necessary, to remove all traces of adhesive.

4. Wipe surfaces clean with a Kimwipe or Kleenex dipped in solvent.

5. NOTE: The accelerometer base must not be filed, sanded, roughened, or edges burred during removal of the cement. A rough mounting surface on an acceleometer can result in poor frequency response and an increase in transverse sensitivity.

* Sold in USA and Canada by distributors of Vigor Company, Divison of B. Jadow & Sons, Inc., New York, NY 10010.





A534

APPLYING ACCELEROMETER CABLE NOISE SPECIFICATIONS TO TEST SITUATIONS

INTRODUCTION

Cables play a vital role in accelerometer measuring systems. Cables can generate noise when subjected to the vibration environment they have to measure. If the noisy cable is on a control accelerometer, the specimen can be undertested. If it is on a test accelerometer, the vibration can be overstated. Either experience is costly.

This paper presents Endevco's cable noise specification and shows how it can be used to predict worst-case vibration-induced cable noise in a given installation. Precise calculations are not possible because of the many variables involved.

CABLE TESTING

ISA has outlined a cable test in RP 37.2, Para. 5.3.2. The test consists basically of suspending a weight from a length of cable, dropping the weight a prescribed distance and measuring the charge generated. This test method has several drawbacks. It is not highly repeatable and one must make several drops to obtain an average result. The test is basically a sampling test and cable is seldom consistent throughout a reel. Generally, tests are made only at the ends of the reel, while hundreds of feet in the middle go unverified. Finally, the test does not closely simulate conditions during use.

Recognizing that the quality of each foot of cable can significantly affect the apparent performance of an accelerometer, Endevco's Quality Control Department long ago developed a rigorous procurement specification and a unique continuous 100% method of testing cable. The principle is the same as ISA's, repeatedly flexing the cable under a prescribed amount of tension. Results are more accurate and more repeatable, and every inch of cable is tested. Any reject sections of the reel are discarded

Endevco's specification for the popular 3090C cable is 1.5 pC pk-to-pk maximum. Because the test is about seven times more stringent, this specification is equivalent to about 0.22 pC per RP 37.2, and performance can be guaranteed for each cable because the whole reel is tested. In practice, the noise figure will be even lower because each cable assembly is marked with the maximum noise detected over the entire reel.

NOISE PREDICTION

We cannot promise a maximum noise figure for specific accelerometer installations because of the many variables involved, but we have developed some guidelines to help predict cable noise in certain tests.

1. Cable noise tends to be a low frequency phenomenon. Very little noise is generated above 200 Hz using our simulation techniques. Figure 1 shows typical noise figure as a function of frequency for 3090C cable.

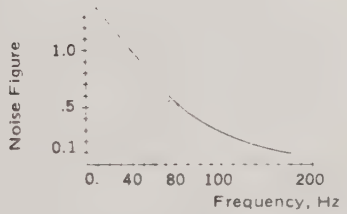


Figure 1. Noise figure vs frequency for 3090C cable

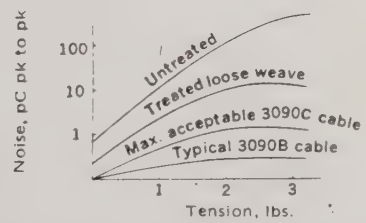


Figure 2. Noise vs tension for 3 ft section of unsupported cable vibrated at 20 g, 40 Hz

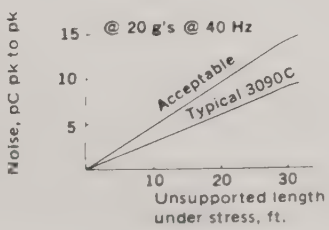


Figure 3. Noise vs unsupported length for 3090C cable vibrated at 20 g 40 Hz

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2. Cable noise increases with increasing tension up to approximately 2.2 lbs (our test point). Beyond this point it tends to be constant. Variation in cable noise with increasing tension is illustrated in Figure 2 for a test length of 3 ft at 20 g, 40 Hz vibration.

3. Cable noise increases with the number of feet stressed, up to approximately 30 ft. Typical variation is shown in Figure 3 for a sample of unsupported 3090C cable vibrated to 20g, 40 Hz.

4. Maximum noise from a cable seems to be limited by the construction of the cable. A noise level of 1.5 pC pk-to-pk at 20 g, 2 lbs tension on a 3 ft section of 3090C cable (Figure 2) is approximately the saturation point. Increasing the g level does not significantly increase noise level.

Assume a user wanted to predict maximum potential contribution to error due to Endevco 3090C cable in this application: the cable has a 3-inch service loop between the transducer and the first cable tiedown and thereafter is tied down to a structural member vibrating at 10 g, 80 Hz, and the cable has approximately 2 lbs of tension (probably higher than would be seen in actual use).

From Figure 2 you can see that a 3 ft section with a tension of 2 lbs vibrated at 20 g, 40 Hz will produce a noise of 1.5 (max) pC pk-to-pk. At 10 g's you can expect only half the output, or 0.75 pC. From Figure 1 you will find that you get only 50% of the output at 80 Hz that you would expect at 40 Hz, or 0.375 pC. A 30 ft unrestrained cable would generate 10 times that amount or 37.5 pC pk-to-pk. This represents a worst-case noise floor of about 0.4 g pk-to-pk when using a 100 pC/g sensitivity accelerometer, decreasing to 0.04 g for a 1000 pC/g accelerometer. Note that cable support along its entire length helps shorten unrestrained length and reduce noise level.

A rigorous set of curves covering all conditions such as shock does not exist at this time. The existing data should reinforce the precautions that most users recognize as important in taking valid data, i.e.

1. Do not leave tension in the cable when restraining it.
2. Do not leave loose loops to flop around during test.
3. Do not leave extensive twist in cable because it acts much like direct tension.
4. Minimize the length of cable under stress.
5. Use Endevco 100% tested low-noise cable assemblies, such as 3090C, 3060A and 3091D.

SUMMARY

Because the costs that result from poor data are so high, every precaution should be taken to use low-noise cable and to install it properly. This is especially important when measuring at low frequencies or when integrating signals for displacement measurements.

Noise Suppression and Prevention in Piezoelectric Transducer Systems

TP 270

Jon Wilson, Endevco®, San Juan Capistrano, California

A common problem in shock and vibration measuring systems is noise generated by ground loops and by pickup from electrostatic and electromagnetic fields. This article reviews the mechanisms of noise generation and suggests how such noise can be prevented or suppressed.

Capacitively Coupled Noise. Presence of a varying electrostatic field (difference in potential) between two conductors coupled electrically by some stray capacitance is a prominent source of noise in piezoelectric transducer systems. For example, two pins in a connector act as plates of a capacitor and the mounting insulator is the dielectric. The pins are susceptible to noise pickup if they are not properly shielded.

Magnetically Coupled Noise. A varying magnetic field in the vicinity of a signal path is a source of noise in almost all measurement systems. If one of the pins above is conducting an ac current, there exists a magnetic field around it which can induce noise into the signal being carried on the other pin.

Current Coupled Noise. Installations where the signal current and other currents use a common path are also a prominent noise source. Any impedance in this path causes non-signal currents to induce noise into the signal currents. For example, if a conductor were used as both the "low" side of the signal path from a transducer and the "low" side of the ac exitation for another device, the common resistance would develop a component of the ac that would appear with the signal.

Shielding for Capacitive Coupling. Charge amplifiers are widely used in vibration measurement systems because they offer so many advantages. But they are susceptible to electrostatic coupling because they respond directly to charge input. Consider the circuit in Figure 1 showing the schematic of a typical piezoelectric vibration measuring system.

Assume that the transducer has a sensitivity of 10 pC/g and that the vibration level to be measured is approximately 1 g. Assume also an ac electrostatic voltage (e_i) present of 100 V (this can be typical). The charge amplifier measures the total charge appearing at its input, which in this example would be:

$$\begin{aligned} Q &= Q_a \times g + e_i \times C_i \\ &= 10\ pC/g \times 1\ g + 100\ V \times C_i \\ &= 10\ pC + 100 \times C_i\ pC \end{aligned}$$

where C_i is the capacitance, in pF, between the interference source and the charge amplifier input.

This equation indicates that a coupling capacitance of only 0.01 pF will produce an error of 10% in the measurement. To ensure rejection of the electrostatic voltage, the signal lead must be shielded at all times, with the shield connected to the input common of the amplifier.

Shielding for Magnetic Coupling. It is generally more difficult to magnetically shield than to electrostatically shield. The instrumentation engineer must take precautions to ensure that instruments and cables are not located in the vicinity of power transformers, solenoids or motors; and that signal cables are not located in cable troughs with current carrying conductors. To understand the problem, refer to Figure 2.

Circuit (a) illustrates a conductor carrying a current i, lying beside the input signal lines. The flux produces voltages e_1 and e_2 which have the polarities shown (at one particular instant). The magnitudes are:

$$e_1 = d/dt\ (N_1\Ø_1) \qquad e_2 = d/dt\ (N_2\Ø_2)$$

d/dt = rate of change with respect to time

N = number of turns being coupled (essentially one unless there is an excess of signal lead that has been neatly coiled!)

$\Ø$ = number of lines of flux coupling the conductors (a function of the magnitude of i, how close the conductors are located over how great a length, and the effect of magnetic shielding).

If e_1 and e_2 were exactly equal, there would be no effective error signal. But this is seldom the case. A difference voltage usually exists, and it is induced into the measurement signal. Note that induced voltage will be larger at higher frequencies, due to the faster rate of change.

Pickup can be suppressed by more direct cable runs through problem environments and by eliminating loops and turns. A large improvement is achieved when the current-carrying conductor is tightly twisted with its return conductor. This results from the cancellation effect of having essentially equal and opposite electromagnetic fields in close proximity, with the resultant reduction of Ø. Similarly, the magnitude of the induced voltage can be reduced by locating a remote charge converter near the transducer and using twisted-pair cables between it and the amplifier. The amplified output also reduces the net effect of induced voltage. Remote converters are also beneficial because their lower output impedance reduces electrostatic coupling problems, but they may reduce signal-to-noise ratio because of their limited maximum signal input.

Isolation for Current Coupling. Current coupled noise occurs when a current other than the vibration signal is introduced into the measurement system. Referring to Figure 3, there would be no current flow in R_t if there were no potential difference between grounds 1 and 2. But grounding is never perfect, and it is usually less than desirable. In instrumentation "jargon," the path from ground 1 through R_t to ground 2 and back to ground 1 through e_g and R_g is called a ground loop. Such a ground loop can occur when a transducer is grounded directly through a test specimen, as well as indirectly through the coaxial cable shield to the amplifier which is grounded to the instrument rack and to the power system ground. When this is allowed to happen, the current flowing in the ground loop will couple a noise signal into the high side of the signal line to the amplifier.

The ground loop path can be suppressed by breaking the circuit at A, B or C so that the system is grounded at only one point. A break at A is achieved by using an insulating stud or washer. A break at B is obtained by using an accelerometer in which the low side of the transducer element and the cable shield are insulated from the transducer case. A break at C is accomplished by amplifier techniques rather than by simple insulation. A study of system grounding techniques and the relative achievements of each is provided in later sections.

Amplifier Configurations. Amplifiers may be identified by the manner in which they handle the grounding of transducer signals. Single-ended amplifiers are most widely used. They have a common path for one side of the signal source, the

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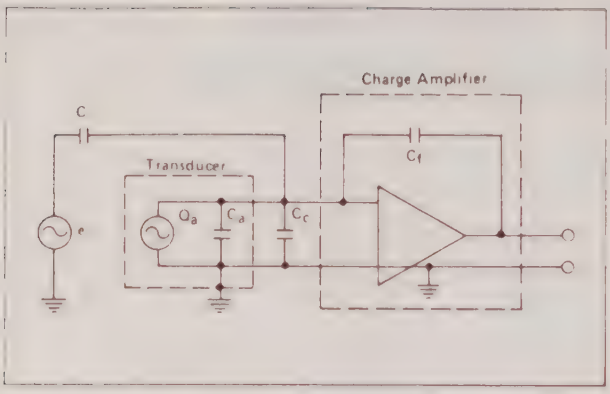

Figure 1. Electrostatic noise is generated by stray capacitance C_1 which couples electrostatical voltage, e_1 into the measurement system.

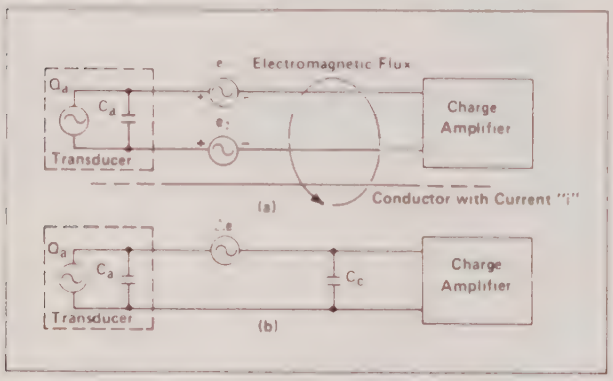

Figure 2. Electromagnetic noise is caused by current-carrying cables (a) or electrical machinery which induces noise into signal cables (b).

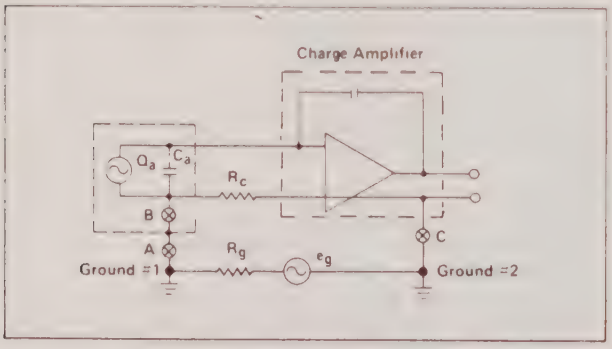

Figure 3. Ground loops occur when measuring systems are grounded at more than one point, causing noise to be introduced into signal cables.

amplifier input and amplifier output. This may be referred to as the low, common or ground side. Referring to Figure 4(a), the low side of the amplifier is "grounded" and in 4(b) "floating."

A single-ended grounded input should be used when the transducer low signal is connected to its case and the transducer is insulated from the specimen. Insulation can be accomplished by the use of an insulating mounting stud. This system provides excellent protection against noise pickup.

When the transducer low signal is grounded to its case, which is in turn grounded through the test specimen, the system should not be grounded again at the amplifier. A single-ended floating amplifier eliminates the amplifier grounding, but a large capacitance to ground may still exist. Therefore, there may be poor protection against ground loops. The amplifier in 4(c) is a better solution because the isolation amplifier opens the path from the transducer/amplifier common. This not only breaks the dc path, but it also minimizes the ac (capacitive) path. Floating amplifiers do not provide as good isolation as single-ended grounded amplifiers, yet they are sometimes the only practical way to provide isolation.

If the transducer, cabling and charge amplifier are properly designed and correctly grounded, the system usually has a good signal-to-noise ratio. But these precautions may be inadequate for low level measurements in the presence of excessively high electromagnetic noise or when using very long cables. In these situations, remote charge converters are available for location near the sensor so that the majority of the line is driven from a low impedance source. Remote charge converters, like the circuits in integral electronic accelerometers, have limited dynamic range and limited slew rate as well as temperature limitations. In applications where these factors are critical to performance of the system, a so-called differential charge amplifier may be required.

Differential amplifiers reject common mode signals; i.e.

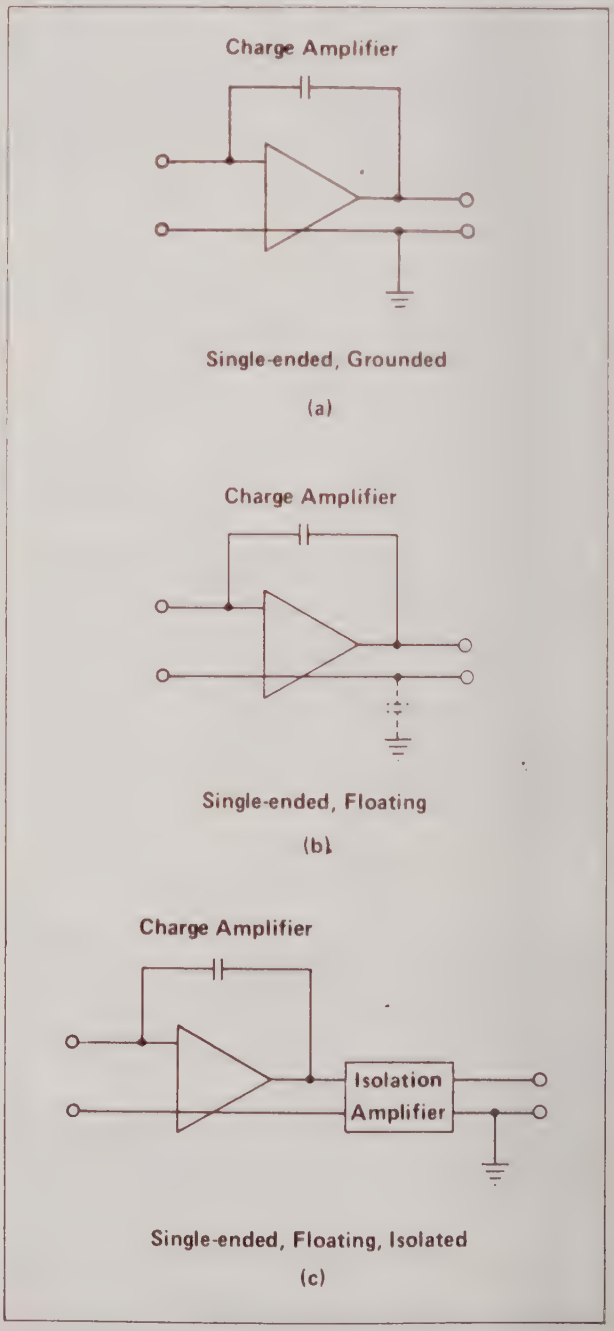

Figure 4. Single-ended amplifiers are available with the input common path either grounded or floating.

non-data signals present on both conductors of a signal line. Unlike single-ended amplifiers which amplify the total signal between their input terminals, differential amplifiers amplify only the difference signal. Traditional differential amplifiers shown in Figure 5(a) and (b) use symmetrical capacitive feedback circuits, but the symmetry is easily disrupted by a change in gain or change of cable or transducer. And they require use of specially-balanced differential accelerometers.

Figure 5(c) illustrates the differential charge amplifier. It overcomes symmetry problems and has proven to be highly satisfactory. Unlike common laboratory differential amplifiers, differential charge amplifiers do not reject the common mode signal. They equally amplify the two individual signals with respect to ground and differentially sum the resultants. The first amplifier (charge converter) is floating and is shielded with respect to the output ground. It provides a stable high level source for the second amplifier, which is a "differential in, single-ended out" voltage amplifier. Because the two amplifiers are integrally assembled, symmetrical configuration is maintained, and the higher operating level allows lower impedance circuitry so that lack of symmetry due to reactive effects is greatly reduced. Therefore, a high degree of common mode suppression is achieved with much less difficulty than with conventional differential amplifier systems. This is the design used in Endevco charge amplifiers, such as the 2735 and 6633. These amplifiers can also be operated in the single-ended grounded input mode.

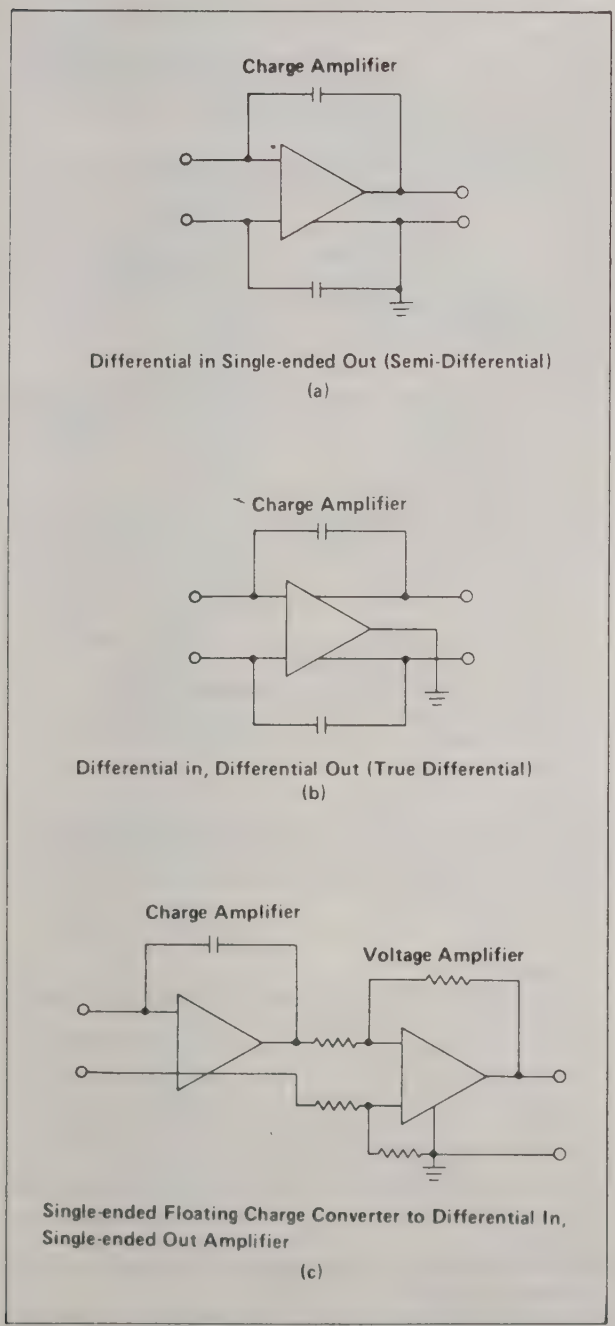

Figure 5. Differential amplifiers provide common mode rejection. The design shown in (c) is best suited to industrial applications.

A Study of Grounding Configurations

Case-Grounded Transducer / Insulated Mounting / Single-Ended Grounded Amplifier. Generally, a case-grounded accelerometer with insulated mounting gives the best protection against pickup induced by ground-loop currents. The system should terminate with a single-ended grounded amplifier. The electrical equivalent of this system is shown in Figure 6.

The accelerometer has an inherent capacitance C_h between the case and the signal side of the crystal (actually the crystal capacitance). It would normally be susceptible to electrostatic pickup, but the insulated mounting restricts ground-loop currents to small values and to a path through signal ground as illustrated. The error introduced is negligible, typically less than 0.001 g (equivalent)/V for 60 and 400 Hz power line frequencies.

Manufacturers offer a variety of insulated mounting studs and washers as well as cementing studs which may be attached to the specimen with an insulating adhesive. Some case-grounded accelerometers have an integral insulating stud or washer.

Because insulating studs lower the mounted resonance frequency and therefore the upper frequency limit by 15 to 30% compared to that available with grounded studs, it is sometimes necessary to use a grounded stud. Or, high temperatures may prevent the use of insulating adhesives.

Case-Isolated Transducer / Grounded Mounting / Single-Ended Grounded Amplifier. Accelerometers with their electrical connectors insulated from the case may be more susceptible to noise pickup than case-grounded accelerometers. The electrical schematic of such a system is shown in Figure 7. There is no significant effect from coupling E_g through C_{in}. But the possibility of capacitance C_h from the case to the signal side of the crystal makes the circuit highly susceptible to pickup induced by E_g. This requires careful design of the accellerometer to to minimize C_h.

Case-Grounded Transducer / Grounded Mounting / Single-Ended Grounded Amplifier. This system shown in Figure 8 has two grounds and is, therefore, highly susceptible to ground loops. It is the most noise prone method of installing and connecting accelerometers. If a potential E_g exists between the two grounds, and it probably does, there is no alternative except to break the ground loop circuit.

Case-Grounded Transducer / Grounded Mounting / Floating Amplifier. If a case-grounded transducer must be grounded through the test specimen, a floating amplifier should be used to ensure a single system ground, see Figure 9. The system may still be susceptible to ground loops because of imperfect grounding at the amplifier output unless an isolation amplifier is used, as in Figure 4(c). This feature is incorporated in the Endevco 2735 Charge Amplifier, whose differential amplifier configuration shown in Figure 5(c) also protects against common mode noise. This is the best alternative to the system consisting of case-grounded transducer, insulated mounting and single-ended grounded amplifier.

Case-Isolated Transducer / Insulated Mounting / Floating Amplifier. This system has no ground and is the logical recipient of spurious noise and ground loops from instruments, motors and other electrical equipment on the same power line.

Case-Grounded Transducer / Insulated Mounting / Floating Amplifier. This system also lacks a ground connection

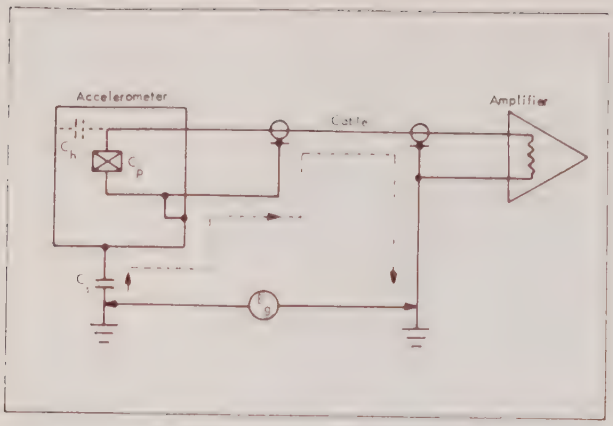

Figure 6. Case-grounded accelerometer with insulated mounting stud and single-ended grounded amplifier provides excellent protection against pickup induced by ground loops and capacitive coupling

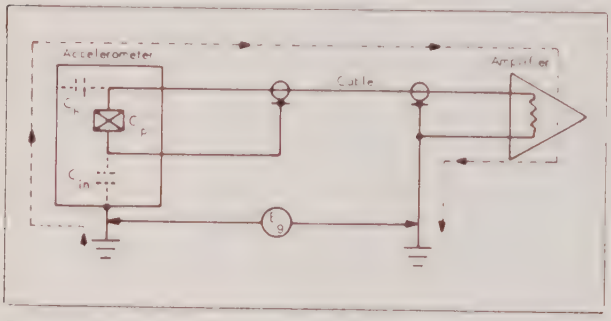

Figure 7. Case-isolated accelerometer with grounded mounting and single-ended grounded amplifier is susceptible to noise pickup through internal stray capacitance.

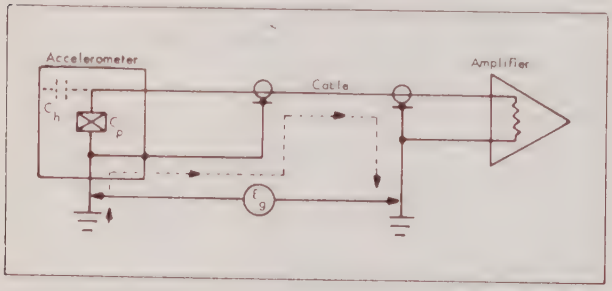

Figure 8. Measuring systems grounded at the transducer and at the amplifier are highly susceptible to noise induced by ground loops.

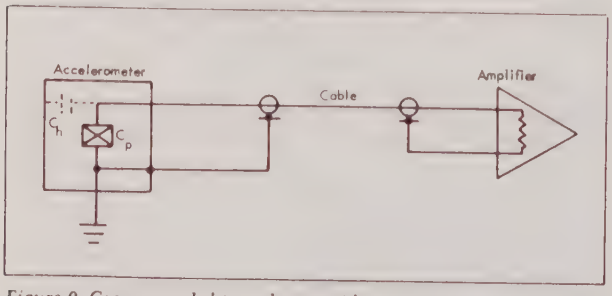

Figure 9. Case-grounded transducers with grounded mounting require floating or differential charge amplifiers.

and is susceptible to pickup from other equipment on the same power line.

A Quantitative Evaluation of Noise Suppression

Various instrument systems and ground configurations have been discussed qualitatively. Here, let us perform a quantitative comparison.

Consider a system consisting of a transducer, a coaxial connecting cable and a charge amplifier which exhibit the following parameters:

Transducer Capacitance	1000 pF
Cable Capacitance	15,000 pF (500 ft.)
Cable Resistance	8 ohms
Resistance Between Grounding Points	10 ohms
Insulating Stud Leakage Resistance	100 megohms
Capacitance	70 pF
Floating Transducer Coupling Capacitance to Common	5 pF
Coupling Capacitance to Signal Lead	5 pF
Coupling Capacitance Unbalance	0.5 pF
Differential Charge Amplifier Feedback Capacitance	500 pF
Floating Charge Amplifier Resistance Between Grounds	50 megohms
Capacitance Between Grounds	200 pF

Assume a 50 Hz interface voltage and a voltage difference between grounding points of 1 V.

A comparison of the current coupled noise magnitude for various system configurations is given in the Table below. This is a typical set of values. The magnitudes will differ significantly for other test conditions, but the relative magnitudes serve to rank order the effectiveness of the various systems in protecting against noise pickup.

The Table indicates that a case-grounded transducer with an insulating stud and a single-ended grounded amplifier provides excellent protection. It is the simplest system available for laboratory and field use. If insulated stud mounting is not practical, use a case-grounded transducer with grounded mounting and a differential charge amplifier. With either system, a remote charge converter will significantly improve signal-to-noise ratio.

System	Case-Grounded Transducer	Case-Isolated Transducer
Grounded mounting, single-ended, grounded charge amplifier	3600 pC	5pC
Grounded mounting, single-ended, charge amplifier with remote charge converter (Endevco 2735 and 2731B)	134 pC	5 pC
Insulating stud, single-ended, grounded charge amplifier (Endevco 2735)	1.8×10^{3} pC	5 pC
Insulating stud, single-ended charge amplifier with remote charge converter (Endevco 2735 and 2731B)	6.8×10^{-5} pC	5 pC
Grounded mounting, true differential charge amplifier	500 pC	0.5 pC
Grounded mounting, semi-differential charge amplifier	2.4×10^{-2} pC	0.5 pC
Grounded mounting, differential charge amplifier (Endevco 2735)	1.0×10^{-2} pC	0.5 pC
Grounded mounting, differential charge amplifier with remote charge converter (Endevco 2735 and 2731B)	1.8×10^{-4} pC	5 pC

Summary

A few simple rules will help minimize noise pickup in most vibration measurement systems.

1. Use high quality coaxial cable and coaxial connectors at each electrical connection.
2. Ground the system at a single point. Preferably, choose a point where the ground can be controlled and positive.
3. Avoid placement of cables in cable troughs or harnesses that contain power or high current conductors.
4. Avoid running cables close to large electromagnetic sources, and avoid long cable runs in difficult environments.
5. Use a remote charge converter if the susceptibility to noise pickup is high.
6. Last, but not least, choose a high sensitivity accelerometer to reduce the effect of noise pickup on signal-to-noise ratio.

ENDEVCO REPAIR SERVICE POLICY

Endevco maintains factory service for repair of all Endevco instruments. To obtain repair or replacement of a defective instrument, return the instrument to the factory:

1. Properly Packaged.

2. Shipping and insurance charges prepaid.

3. Warranty:
   Endevco warrants each new electronic instrument and transducer to be free from defects in material and workmanship. Please refer to the appropriate Warranty Policies for the warranty terms and warranty period. This warranty is extended to the original purchaser only.

   Instruments returned under warranty will be repaired or replaced, at no charge, if the failure is due to defective material or workmanship and the unit(s) is returned within the time period and conditions of Endevco's warranty policy.

4. Out of Warranty:
   Enclose a purchase order not-to-exceed $150.00 authorizing repair/calibration of the instrument, and a full explanation of the failure or symptoms observed to help us in fixing the problem. (Refer to Report of Failure check list on the reverse side of the appropriate Warranty policy.)

   The instrument will be repaired/calibrated, returned and invoiced for the actual repair charges. If the instrument cannot be repaired for $150.00 or less, Endevco will submit a written quotation for the cost of repair and/or a replacement unit.

5. Endevco Transducer Trade-In Policy:
   Used Endevco transducers may be traded in for new replacement transducers. Transducers are replaced at 85% of the purchase price based on the quantity returned of the same model. When traded against a different model/manufacturer transducer, a maximum trade-in allowance of $50.00 for each unit returned will be allowed.

   This trade-in policy covers all standard:
   - Piezoelectric Accelerometers
   - Piezoresistive Accelerometers
   - Integral Electronic Piezoelectric Accelerometers
   - Pressure Transducers

NOTE: All instruments which have been evaluated and a quotation provided by Endevco, require the return of a purchase order, within 45 days authorizing repair or replacement of the instrument. The instrument will be returned to the owner without repair if a purchase order has not been received within 60 days of quotation. See attached flow chart.
Endevco has a minimum service charge of $100.00 per order or $35.00 per unit

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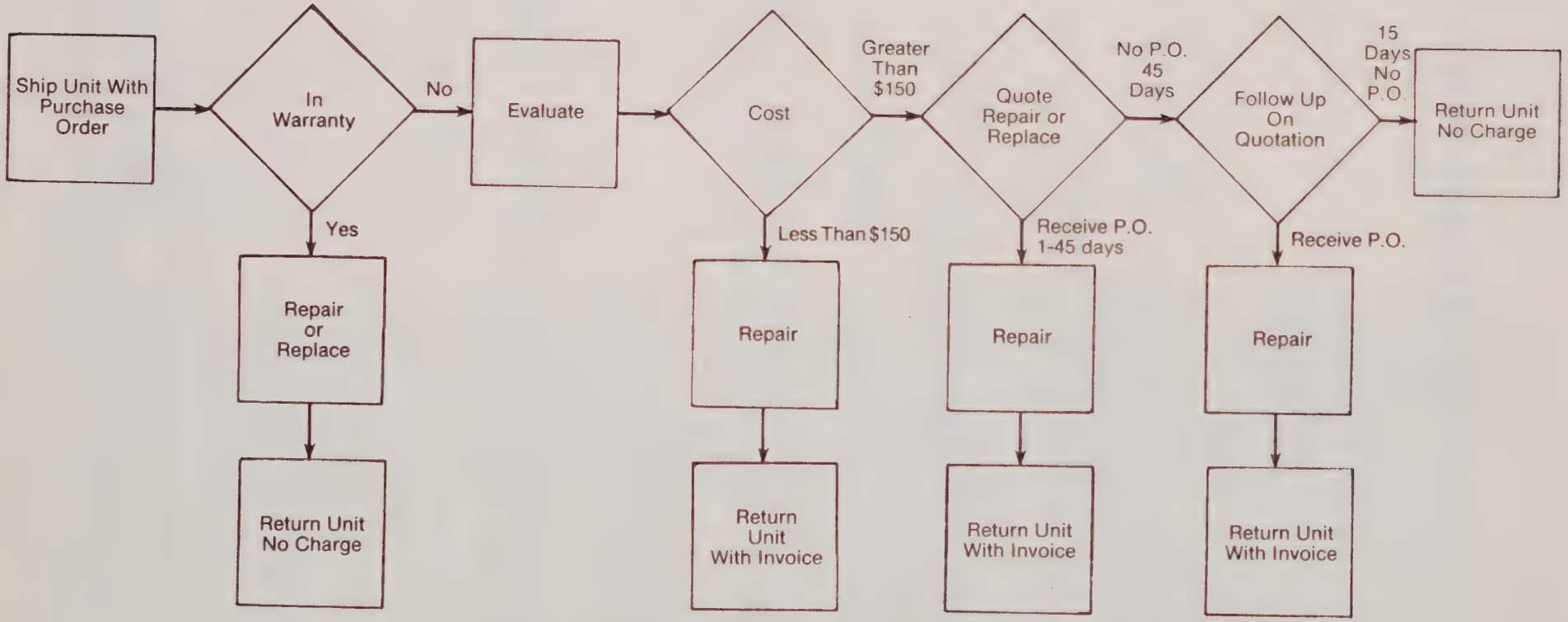
REPAIR SERVICE FLOW CHART



ENDEVCO

WARRANTY

Piezoelectric Transducer

ENDEVCO®, a Division of Becton, Dickinson and Company, warrants each new piezoelectric transducer (other than 6200 series) to be free from defects in material and workmanship for three years from date of shipment to the original purchaser. This warranty does not extend to units that have been misused or used in violation of ENDEVCO recommendations, or to units that have been altered or repaired outside ENDEVCO's factory. Defects covered by this warranty will be remedied at no charge, provided the instrument is delivered to the factory with all transportation charges prepaid. If, upon examination, it is found that the defect is not within the scope of this warranty, a statement of repair charges and a request for authorization to proceed with the repair will be submitted.

The above warranty period does not extend to new cable assemblies, mounting accessories, connectors and other non-serialized products which are only warranted to meet applicable ENDEVCO specifications when shipped from our factory.

The liability of ENDEVCO under this warranty is limited to repair or replacement of any defective instrument within the sole discretion of ENDEVCO. The foregoing warranty is exclusive and in lieu of all other warranties express or implied.

Ron S. Cappello

Director,
Quality Assurance

President

ENDEVCO

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OF BECTON DICKINSON AND COMPANY

REPORT OF FAILURE SYMPTOM
PIEZOELECTRIC ACCELEROMETER

Customer _____ Date _____

Endevco Accelerometer Model No. _____ Serial No. _____

☐ This unit is not for repair but for trade-in discount only

SYMPTOMS OF FAILURE

☐ Obvious Physical Damage:

- ☐ Connector crushed, cross-threaded or missing
- ☐ Mechanical dents and/or breaks
- ☐ Deep gouges in the base with ridges above mounting surface
- ☐ Field modification and/or disassembly
- ☐ Mounting threads damaged or cross-threaded (not used as cement mount)
- ☐ Discoloration due to excess heat
- ☐ Internal rattles
- ☐ Gouges in case
- ☐ Cable damage (if integral part of unit)

☐ Electrically Inoperable

- ☐ Limited full scale operation
- ☐ Open
- ☐ Shorted
- ☐ No output
- ☐ Problem is intermittent

☐ High transverse axis sensitivity (crosstalk)

☐ Sensitivity change _____ % (if known)

☐ Frequency response change

☐ Low resistance (less than 500 megohms)

☐ Other (Explain) _____

_____

_____

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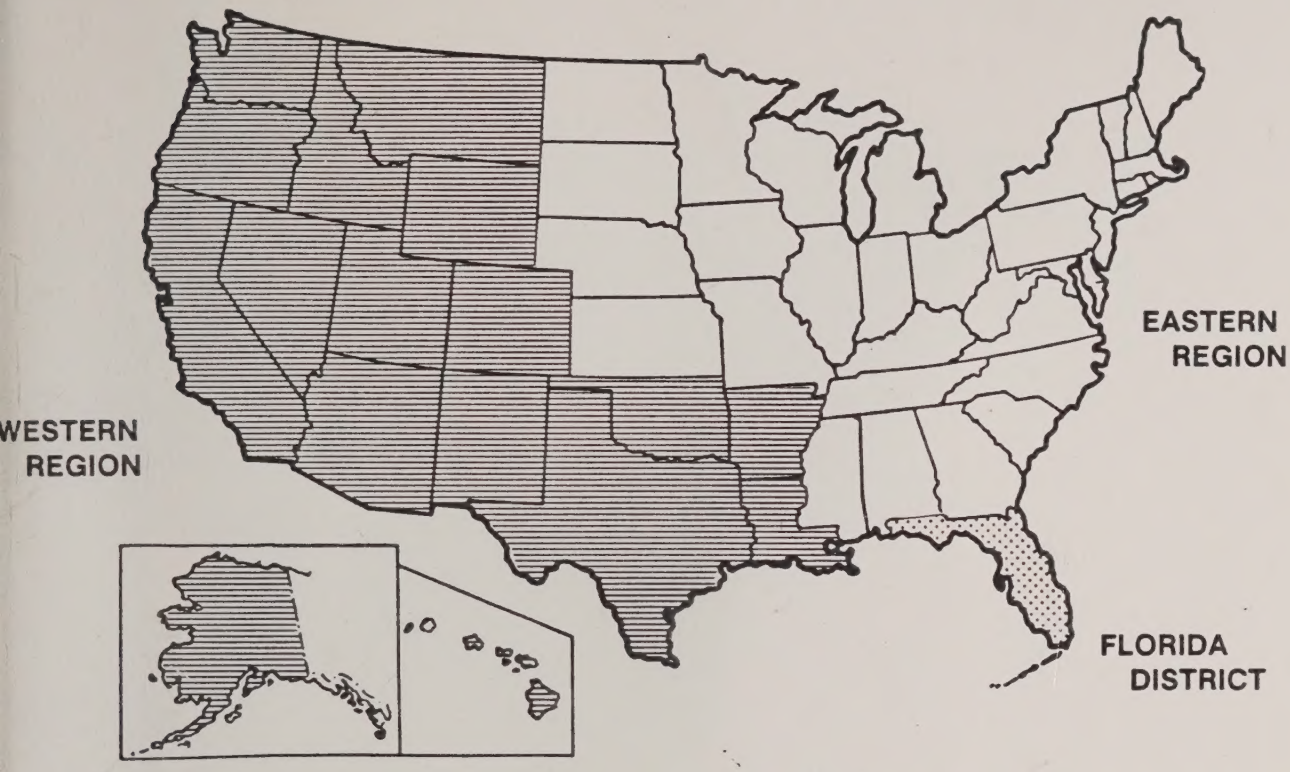

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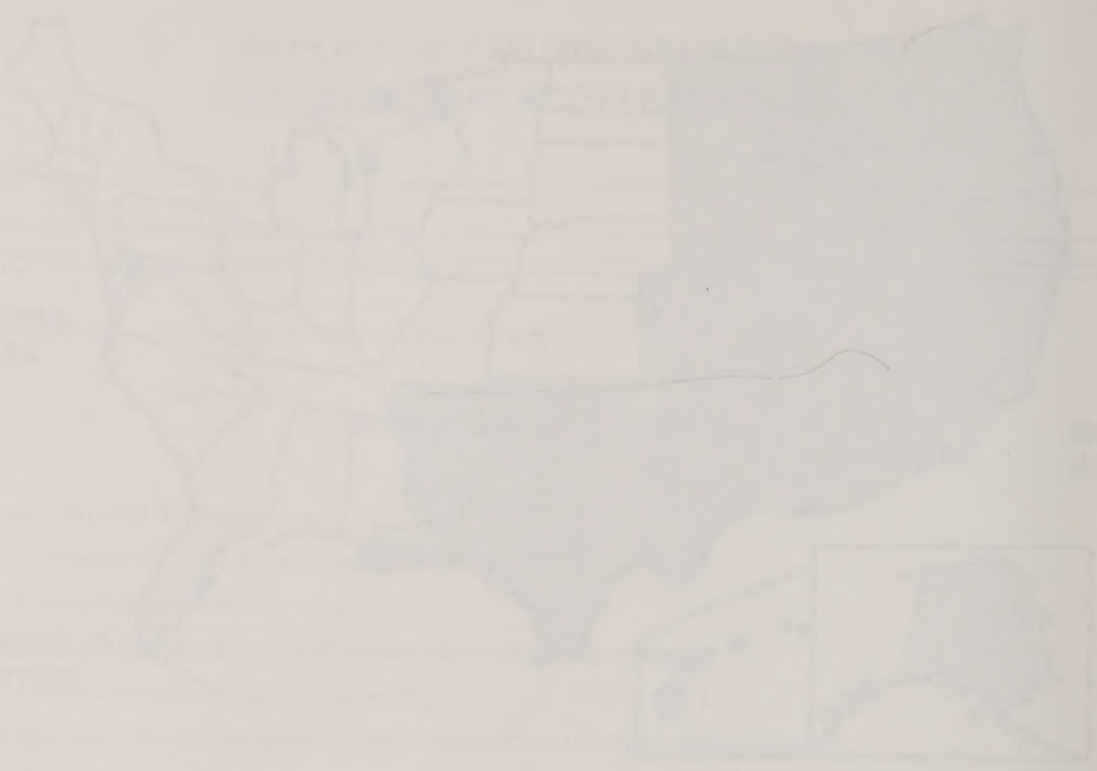
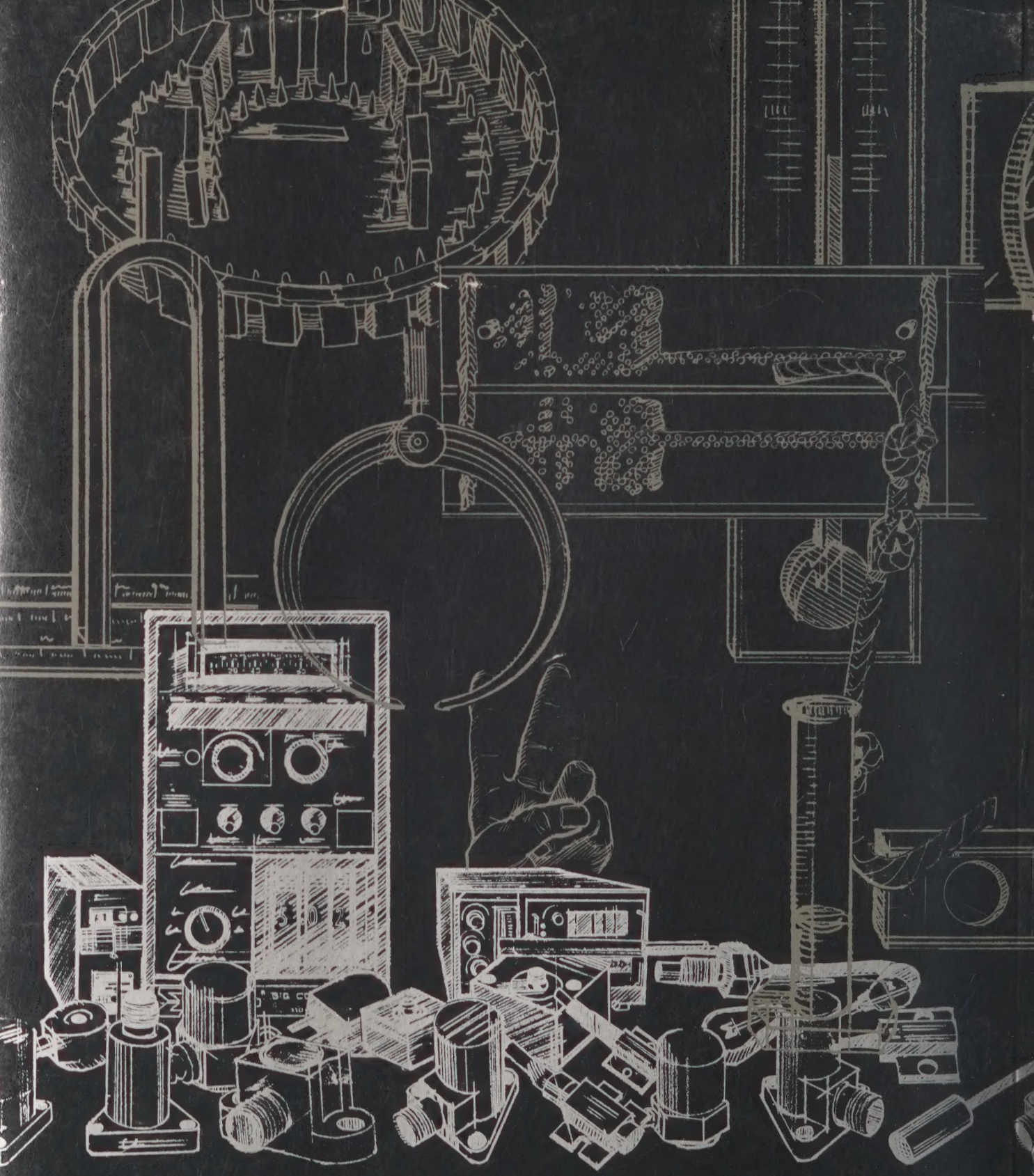
For the name and address of your nearest representative, contact ENDEVCO headquarters in California.





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